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CHAPTER 2 – THE EARTH

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CONTENTS .... PAGE

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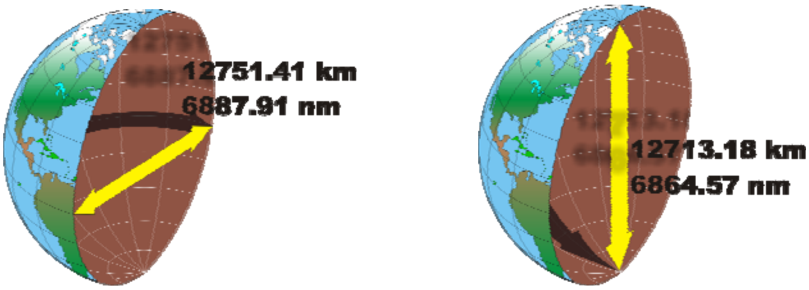
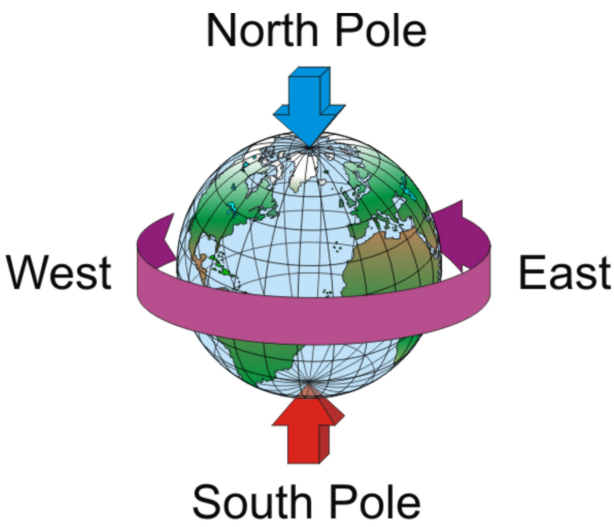
CHAPTER 2 - THE EARTH

INTRODUCTION

The polar diameter is some 43 km less than the equatorial diameter and there are other small distortions and irregularities which must be considered by cartographers and by the designers of the most accurate navigation systems. The shape of the Earth is an oblate spheroid. For most practical purposes in air navigation, the Earth can be considered a **perfect sphere**. In these notes, a spherical shape will be assumed unless specifically stated otherwise.



The Earth rotates on its axis from west to east at a rate of 15.04°/hour relative to a fixed point in space. The spin axis passes through the centre of the Earth, cutting the surface at two points, the north and south poles. The rotation is subject to small perturbations but, for practical purposes, the alignment of the Earth's spin axis remains constant and the rate of rotation is simplified as a 360° rotation in 24 hours.



The Earth also revolves around the Sun in an almost circular elliptical orbit, each revolution taking one year to complete.

POSITION

All forms of navigation involve the orderly progression from one defined point on the Earth's surface to another defined point. Therefore, we need a position reference system to locate every point on the Earth's surface in a manner that is unique, repeatable, and universally accepted. This presents an immediate difficulty, as a sphere is perfectly symmetrical about all its axes, with no obvious 'start point' from which a position reference system could be based.

Every point on the Earth's surface is a point in three-dimensional space, so its definition requires three 'coordinates' measured with respect to three independent axes.

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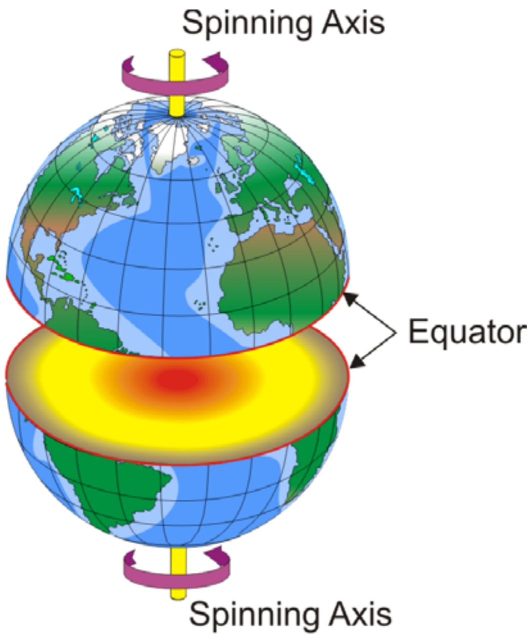
However, in terrestrial navigation we are interested only in positions on or very near the Earth's surface, thus removing the need for one of the coordinate axes. Hence, the problem reduces to one of defining the two remaining coordinates in an acceptable form.

MERIDIANS

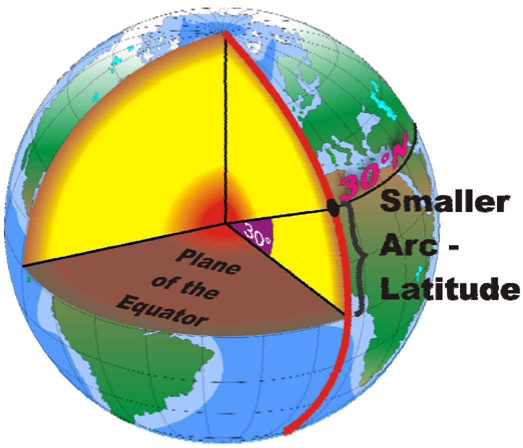
Meridians are the semi-circle centred on the centre of the earth that joins the two poles. The plane of a meridian is parallel to the Earth's spin axis, and hence cuts the equator at right angles.

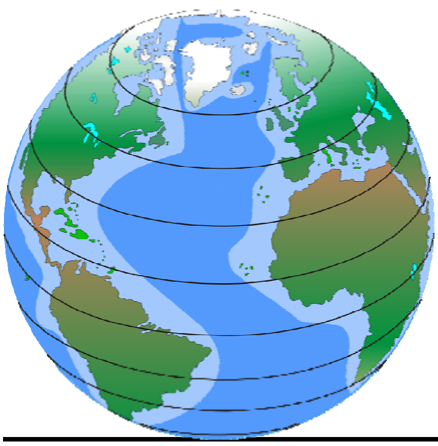


LATITUDE

The equator is a line equidistant to both poles. We use the equator to define one coordinate - the latitude - of every point on the Earth's surface.

Latitude is defined as the angle subtended at the centre of the Earth by the smaller arc of the meridian that passes through the point in question, measured from the equator to the specific point we wish to locate. If the point lies nearer the north pole, the latitude is measured in a positive direction from the equator and the angle is qualified by the suffix 'North'. If the point lies nearer the south pole, the angle of latitude is negative and is qualified by the suffix 'South'. Under this system, the latitude of the equator itself is zero, and of the poles, 90°N and 90°S respectively.





For every value of latitude between these extremes, there are an infinite number of points around the surface of the Earth, all of which are equidistant from the nearer pole. This circular line of points is called a Parallel of Latitude. The plane of all such parallels is parallel to the plane of the equator. Thus, in defining latitude, we have defined a circle upon which the point in question is located.

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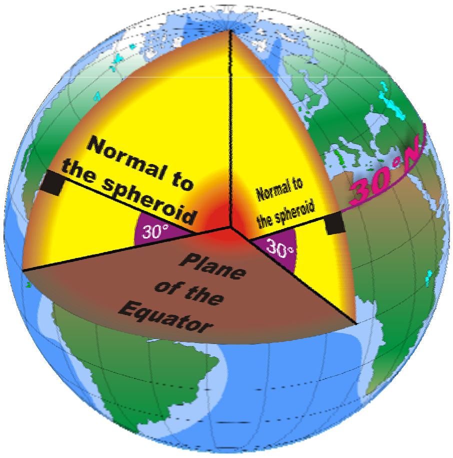
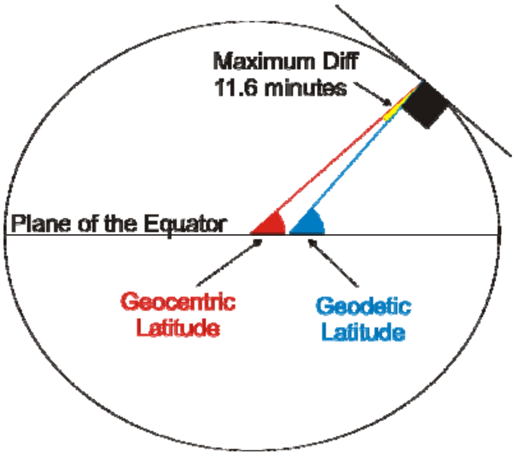
GEOCENTRIC AND GEODETIC LATITUDE

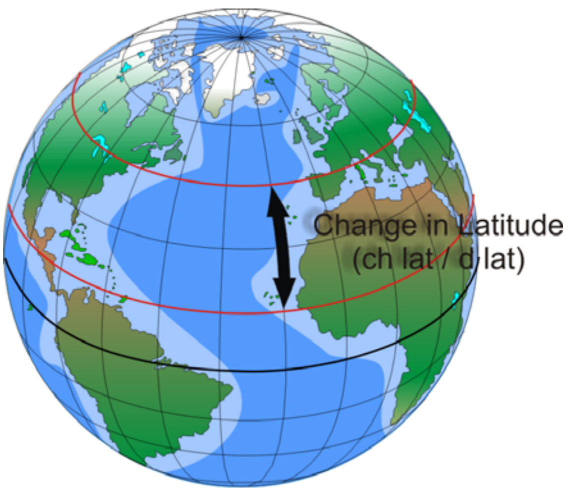


The definition of Latitude given above relies on the earth being a perfect sphere. As seen earlier this is not the case, the earth is an oblate spheroid. Because of this the definition of a latitude must be refined to give us Geodetic (or Geographic) Latitude. Geodetic (or Geographic) Latitude is the smaller angle between the normal (90°) to the meridian at the point on the spheroid and the plane of the equator. This normal line does not necessarily pass through the centre of the spheroid as illustrated in the diagram.



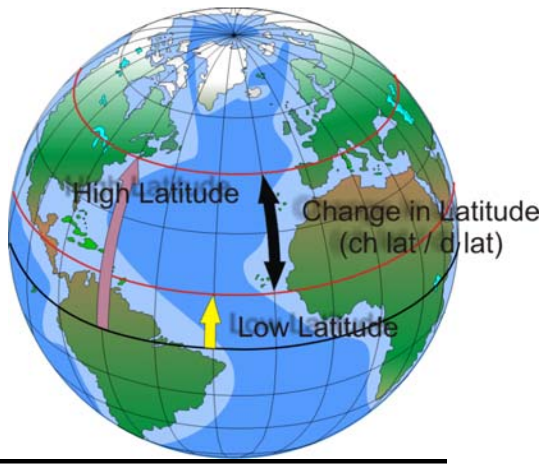
The shape used in this diagram is exaggerated for illustration purposes and the real spheroid is much closer to a sphere than shown. The latitudes plotted on navigation charts are Geodetic Latitudes. The maximum difference between Geocentric and Geodetic Latitudes occurs at approximately 45° N/S and is about 11.6 minutes of arc. This will not affect us in basic navigation, but with more advanced navigation systems such as INS/IRS and GPS it will most definitely have an effect if not considered.

CHANGE IN LATITUDE (*CH LAT / D LAT*)



The change of latitude (ch latitude, or d lat) between two points is the arc of a meridian intercepted between their parallels of latitude. It can be annotated N or S according to the direction of the change from the first point to the second. In this course the direction will have no relevance.

If the two points are on the same side of the equator the ch lat (d lat) is found by subtracting the lesser latitude (low latitude value) from the greater latitude (high latitudes).



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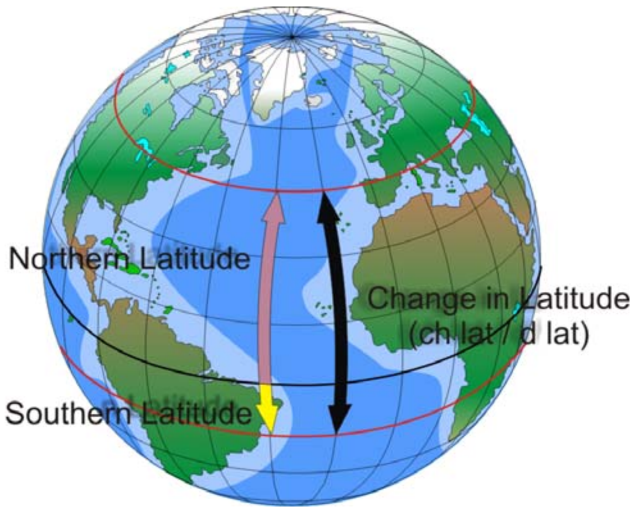
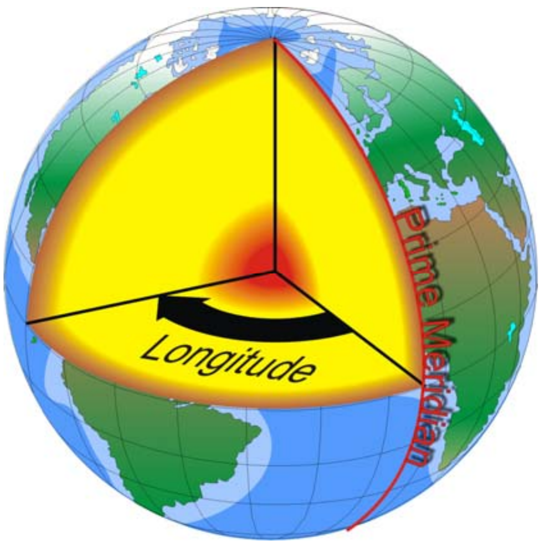


If the two points are on opposite sides of the equator, the ch lat (d lat) is equal to the sum of the northern and southern latitudes.

LONGITUDE

Meridian cut the equator and hence every parallel of latitude at right angles, so is ideal as a second coordinate for position, provided we could find a datum from which to commence measurement. The datum is the meridian that passes through the Royal Greenwich Observatory, located near London in the UK. This meridian is called the Greenwich meridian or prime meridian, and the second coordinate, the longitude, of every point along the Greenwich meridian between the north and south poles, is zero.



The longitude of every other point on the Earth's surface is defined as smaller arc along the Equator, measured from the Greenwich meridian to the meridian of the place in question. This is equivalent to defining longitude as the angle between the plane of the Greenwich meridian and the plane of the local meridian of the particular point. If the point is east of Greenwich i.e. in the direction of the Earth's rotation from Greenwich, its angle of longitude is qualified by the suffix 'East'. If the place is west of Greenwich, the longitude is deemed to be 'West'. Clearly, a meridian will be reached that is both 180° East and 180° West of Greenwich. This is called the Greenwich anti-meridian, or the 'International Date Line', and assumes importance in our subsequent study of time.

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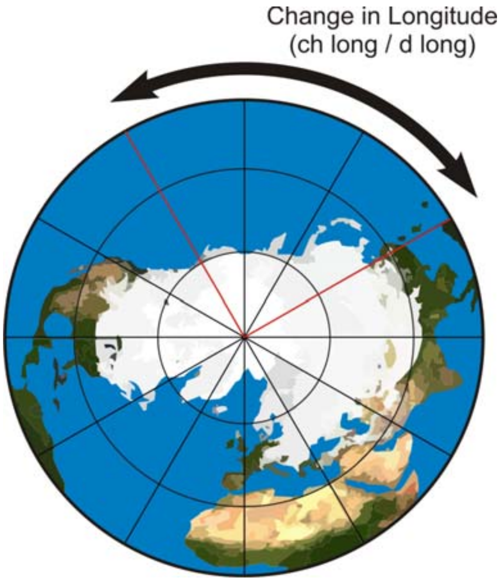
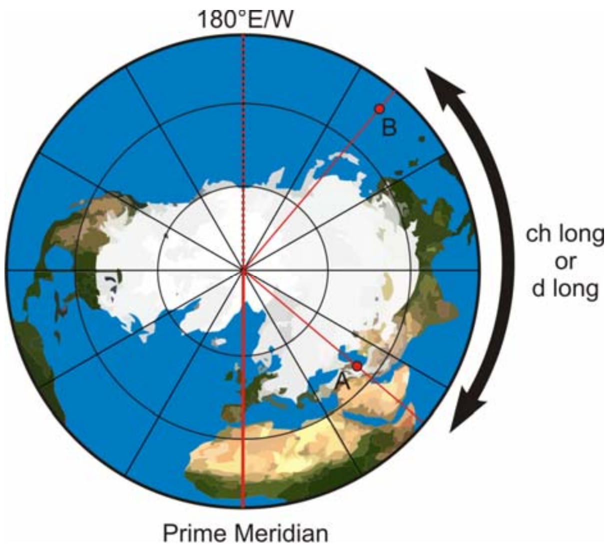
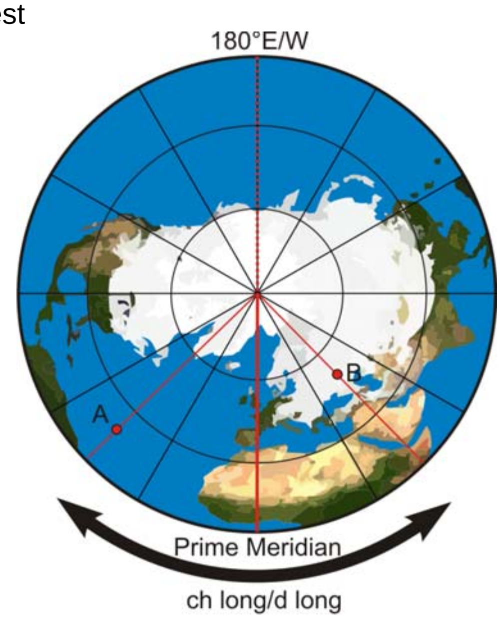
CHANGE IN LONGITUDE (*CH LONG / D LONG*)



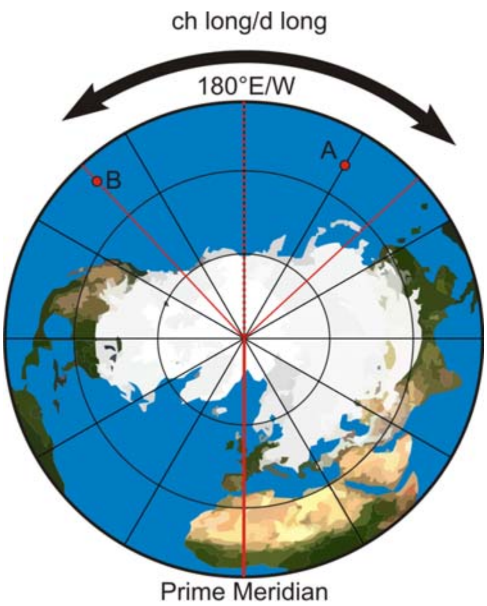
The change of longitude (ch long / d long) between two points is the smaller arc of the equator intercepted by the meridians through the two points. It can be annotated E or W according to the direction of the change from the first point to the second. In this course the direction **will** have relevance in **time calculations**, where the direction will determine if a location is ahead or behind another location.



If two point are in the same hemisphere, either eastern or western hemisphere, the d long is found by calculating the difference between them. In the example to the left, the direction from A to B is East and from B to A is West



If the two points are in different hemispheres, the d long is found by adding their respective longitude values.



By definition the d long is the smaller arc between any two points, therefore, if the sum of their respective longitudes are greater than 180° this sum must be subtracted from 360°.

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POSITION

Using both latitudes and longitudes we have established a grid of numbered lines on the sphere. The grid system formed by the lines of latitude and longitude form a pattern known as a graticule.

At every point on the Earth's surface except the two poles, the local parallel cuts the local meridian at 90 degrees, and knowledge of the latitude and longitude uniquely defines the point. Since all meridians pass through both poles, the concept of longitude at the poles is meaningless, and the poles are uniquely defined in terms of latitude only, i.e. 90°N and 90°S respectively.

The position of Parafield airport for example is written in full as

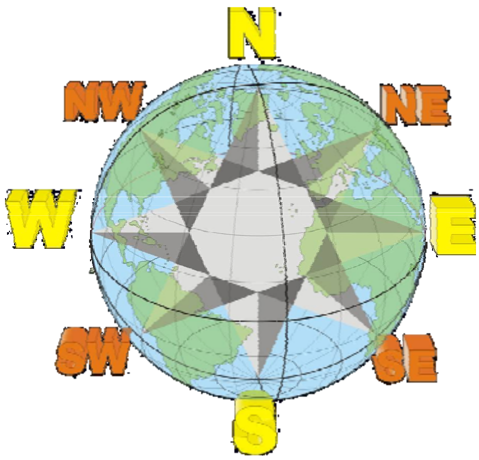
34° 47 '41 " South, 138° 37 '54" East,

signifying that it lies 34° 47'41" south of the equator and 138° 37'54" east of the Greenwich meridian. Nowadays it is much more common to record a position in minutes and decimals, rather than seconds. This is now in widespread use on charts, Jeppesen, ERSA, and for entering of information into a Flight Management Computer (FMC), Inertial Navigation System (INS), or GPS. The same position as above: S34°47.683 E138°37.9

DIRECTION

TRUE HEADING

At every point on the Earth, the local meridian defines the direction from that point to the north (and south) pole. The direction of the North Pole from the point is called 'True North' and provides the primary datum for all direction measurements from that point to any other. To measure direction from one point to another we measure the angle from true north at the start point, clockwise to the line joining the start point with the destination. Hence, bearings from one point to another can take any value between 0° and 359°, with smaller divisions if greater accuracy is required. The so-called 'cardinal' directions, North, South, East and West, are described in this system, as 000°, 090°, 180° and 270° respectively.



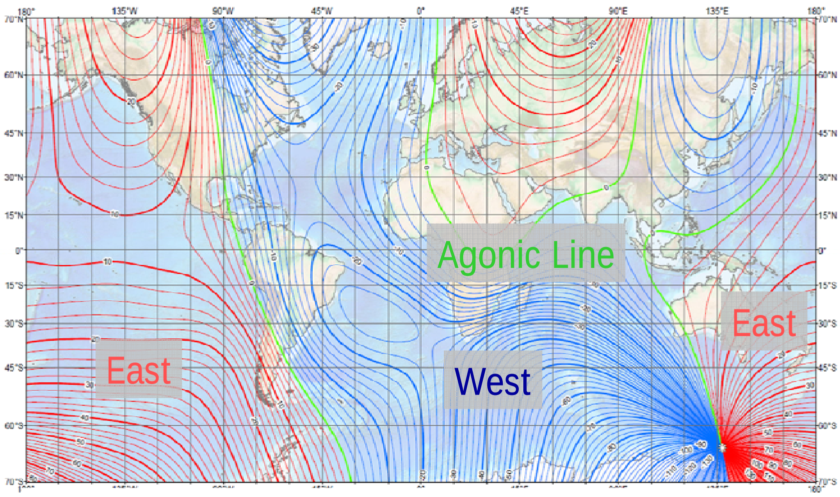
The prefix 'True' signifies that the datum is the Earth's geographic North Pole, and distinguishes true north from other secondary, although sometimes more convenient, directional references in common use.

MAGNETIC NORTH

We have previously mentioned that the preferred method of navigation for many pilots is to steer by the magnetic compass. This makes use of the fact that the Earth itself is a magnet, and hence possesses a magnetic field with which a freely suspended bar magnet will align. Fortunately, the Earth's magnetic north pole lies close to the geographic pole that we previously established as the datum for the measurement of 'true' directions on the Earth's surface.

Therefore, from most locations on the Earth, the direction of the magnetic pole does not differ greatly from true north, and defines the datum that we call 'magnetic north'. Magnetic north is the direction sought by a freely suspended magnet, and provides the datum from which in-flight measurement of direction is achieved using the magnetic compass.

The Earth's north and south magnetic poles are joined by irregular curves called magnetic meridians. The angular difference between the plane of the magnetic meridian and the plane of the geographic meridian at any point is defined as the 'magnetic variation', or just 'variation', at that point. However, variation is usually defined more simply as the angular difference between true north and magnetic north. Isogonals are lines joining points with the same variation value and an Agonic Line joins points with 0° of variation.



Example of a Chart depicting Variation

By convention, variation is measured from true north to magnetic north. If magnetic north lies to the west of true north, variation is 'west', and if it lies to the east of true north, variation is 'east'. See Figure 1.

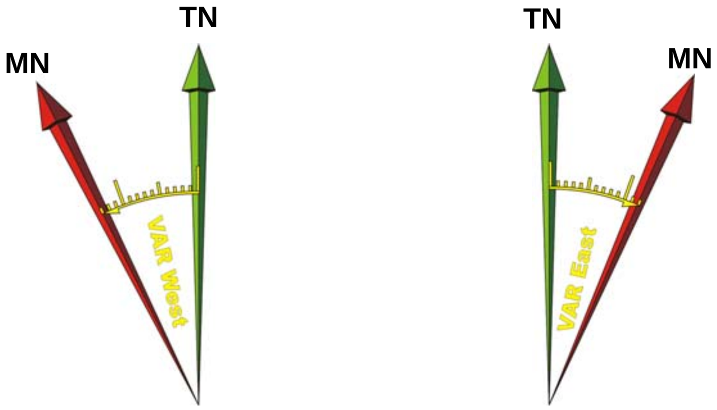


FIGURE 1

Information on magnetic variation at specific locations is obtained from various aeronautical publications, and its value over large areas is depicted on charts, usually in the form of 'isogonals'. Isogonals are usually plotted at 1° intervals, so the value at any position is easily obtained by interpolation.

True north remains the primary datum regarding actual direction over the Earth's surface, the magnetic compass simply providing a convenient means of sensing that direction. Therefore, aviators must be proficient at transferring directional information from one datum to the other. Figure 2 shows the relationships between a constant true heading, and the headings that would be measured by the magnetic compass given differing values of variation.

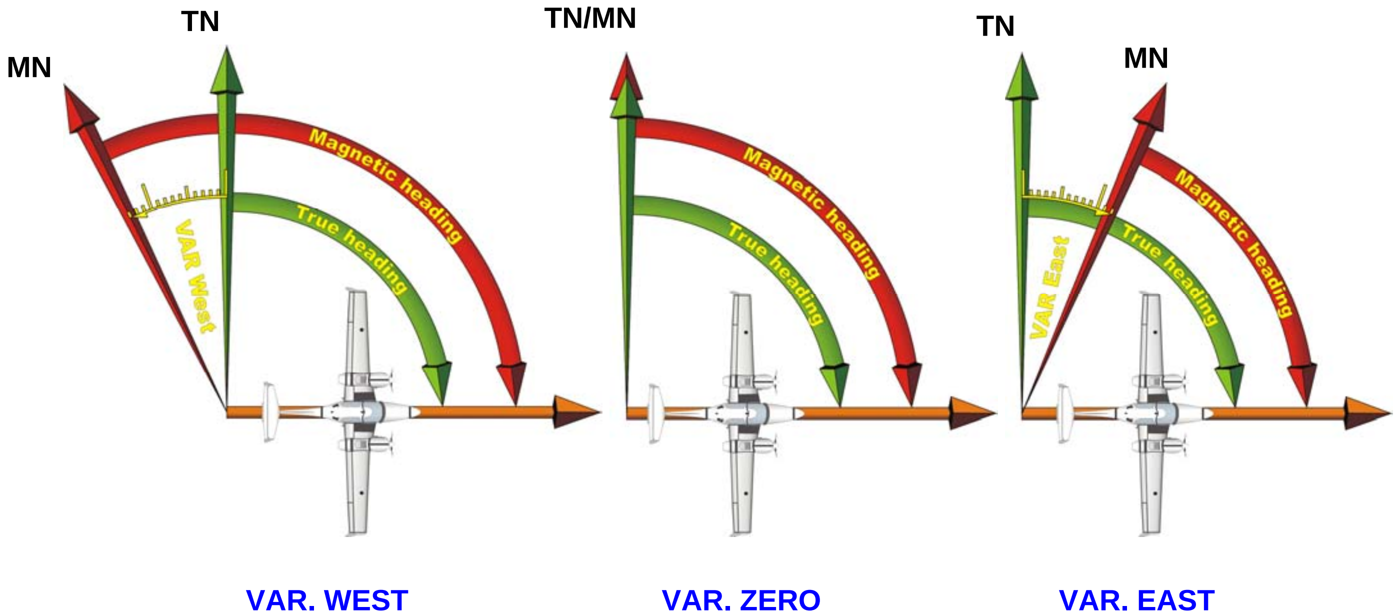


FIGURE 2

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The relationship is conveniently summarised in the following well-known aide memoire:

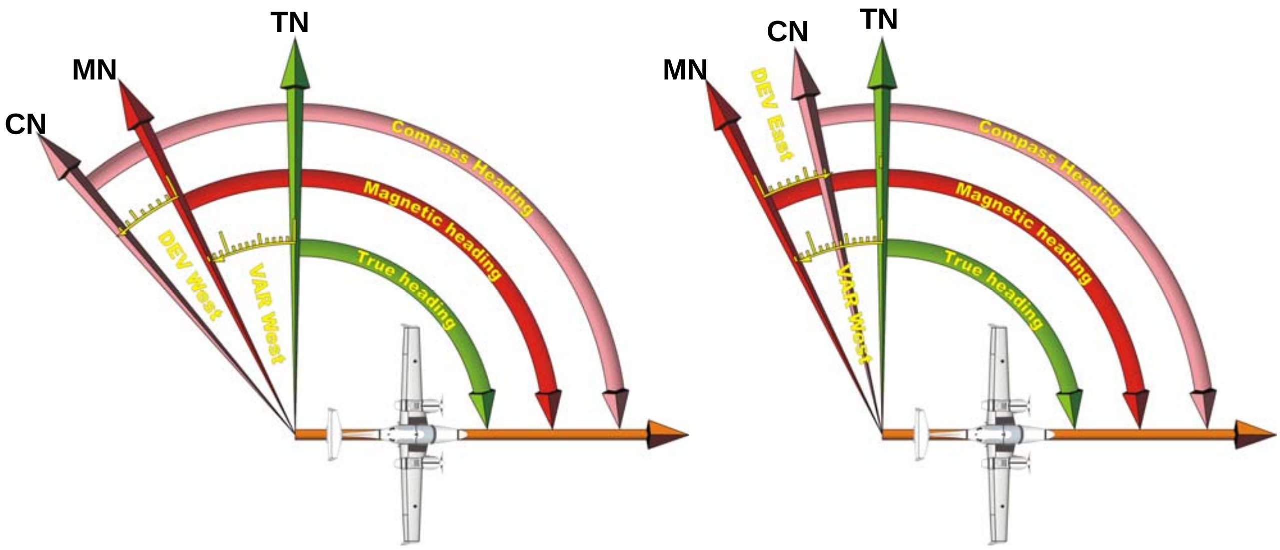
Variation West, Magnetic Best
Variation East, Magnetic Least

COMPASS NORTH

The magnetic compass should, ideally, indicate the direction of magnetic north. However, in addition to the Earth's field, the compass is also subjected to unwanted magnetic fields arising from ferrous metals and electrical circuits contained within the aircraft. This results in an error, and the compass points to 'compass north', the angular divergence from magnetic north is called 'compass deviation' or just 'deviation'. If the compass needle points to the west of magnetic north, deviation is 'west', and if it is east of magnetic north, deviation is 'east'. As before, a simple aide-memoire is available:

Deviation West, Compass Best
Deviation East, Compass Least

Easterly deviation is often depicted as 'positive' and Westerly deviation as 'negative'. This reflects the fact that the correct magnetic heading is obtained by adding east or subtracting west deviation from the compass reading. See Figure 3.



Hdg (M) = Hdg (C) – Dev.

DEV. WEST (negative)

Hdg (M) = Hdg (C) + Dev.

DEV. EAST (positive)

FIGURE 3

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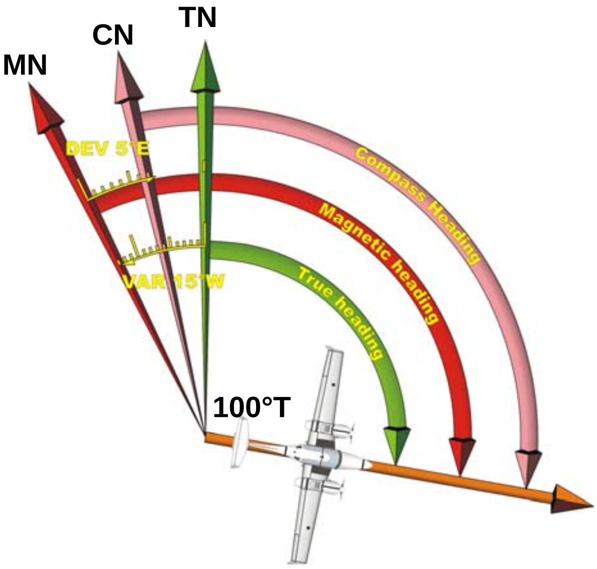
Note that the values of Variation and Deviation are algebraically additive. For instance, consider the problem of steering a heading of 100°T in a area where variation is 15°W, using a compass with deviation 5°E. See Figure 4 below.



Hdg(T) = 100
Var = 15W
$\therefore$ Hdg(M) = 115
Dev = 5E
$\therefore$ Hdg(C) = 110

The same result could be obtained by noting the algebraic sum 15 W + 5E = 10W, and by applying this to the true heading.

FIGURE 4

SUMMARY OF DIRECTIONAL REFERENCES

We have established a ‘hierarchy’ of directional references. Normally true north is the primary datum. The following table may assist in understanding this hierarchy more clearly.

NORTH DATUM	DIFFERENCE	HOW DETERMINED/PRESENTED
TRUE		
	VARIATION	ISOGONALS
MAGNETIC		
	DEVIATION	COMPASS CALIBRATION
COMPASS		

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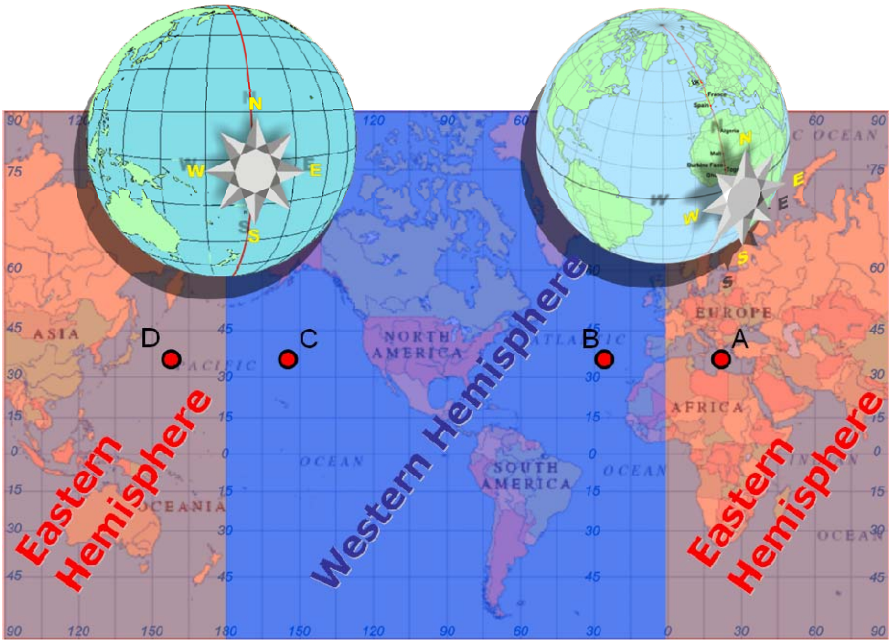
RELATIONSHIP BETWEEN DIFFERENCE IN LONGITUDE AND DIRECTION

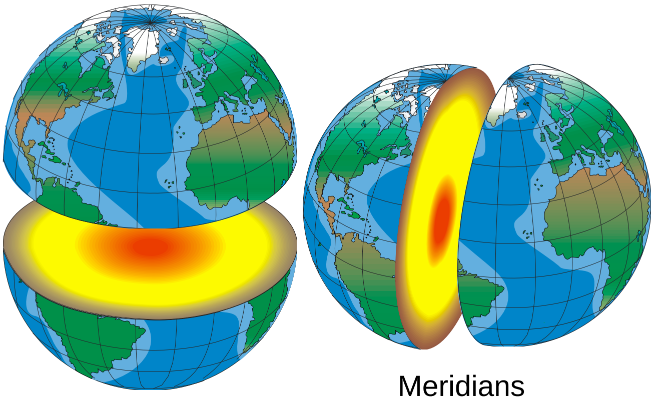
When a diagram is drawn showing the orientation between two points it is important that the direction between the two points is always correct. If one point is in the eastern hemisphere and the other in the western hemisphere there are two possible scenarios:

- If the d long arc crosses the Prime meridian, then the western hemisphere is on the left hand side of the diagram (between points A and B for example).
- If the d long arc crosses the 180°E/W Meridian, then the western hemisphere is on the right hand side of the diagram (between points C and D for example).



LINES ON THE EARTH - THE GREAT CIRCLE

We have already noted that some circles on the Earth have as their centres the centre of the Earth itself. These are called 'Great Circles'. The equator and all the meridians (with their corresponding anti-meridians) are examples. These are aligned with particular reference to the Earth's spin axis but, in general, the plane of a great circle can have any alignment.


Equator
Meridians

Since the centre of all great circles is also the centre of the Earth, all great circles have the radius and circumference of the Earth itself. In other words, all great circles describe circumferences on the Earth's surface, and the plane of every great circle divides the Earth into two equal hemispheres.

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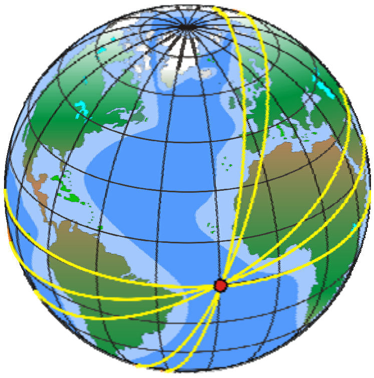
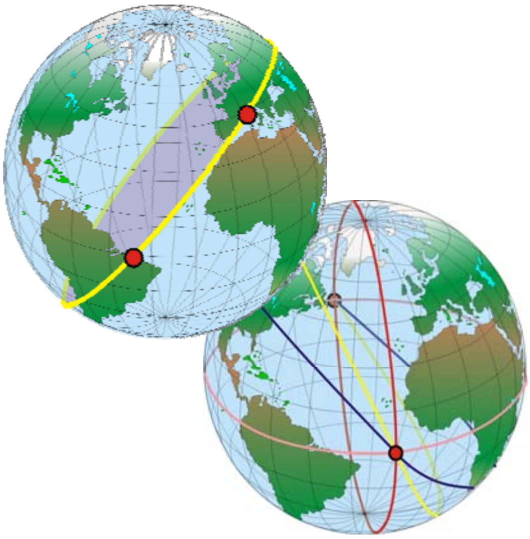
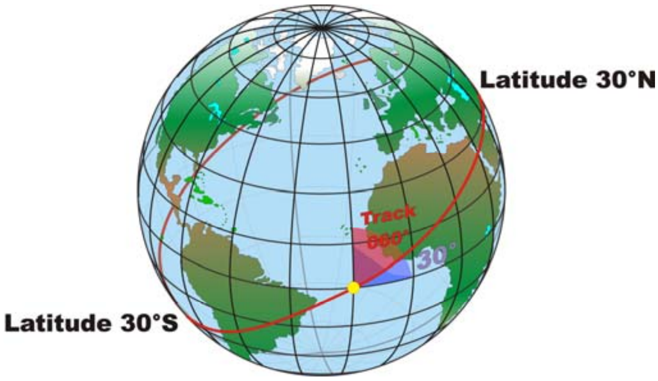
An infinite number of great circles can be drawn through any single point on the Earth. The line joining the point itself with the centre of the Earth provides an axis common to the infinite number of flat planes containing these great circles.





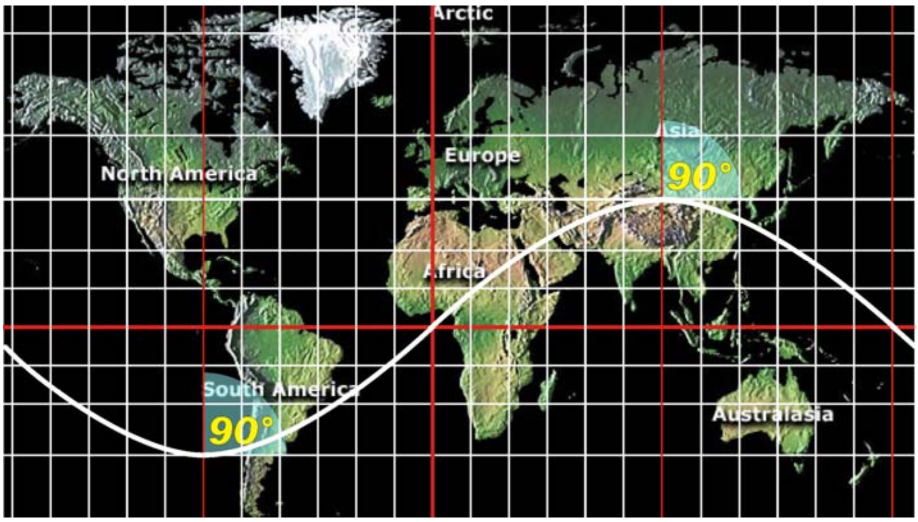
However, with the exception of points diametrically opposed, only one great circle can be drawn between two given points on the Earth's surface.

Since the great circle lies in a plane that passes through the centre of the Earth, it possesses properties of symmetry that enable us to predict its characteristics very easily. We now discuss some of these properties.



All great circle tracks circumnavigate the Earth around its circumference, and a vehicle on such a track passes over the same points along the same track direction during successive transits.

The angle at which the track crosses the Equator is equivalent to the angle between the plane of the great circle and that of the Equator, in other words to the numerical value of the latitudes of the northernmost and southernmost points on the track. These points are called the 'vertices' of the great circle. With the exception of the equator - which has no vertices - one vertex always lies in the northern hemisphere and the other in the southern hemisphere, each bearing the same numerical value of latitude.



At the vertices the track direction changes its orientation from north to south (or vice versa) and, with the exception of the meridians - for which the vertices are the poles - the track orientation at a vertex

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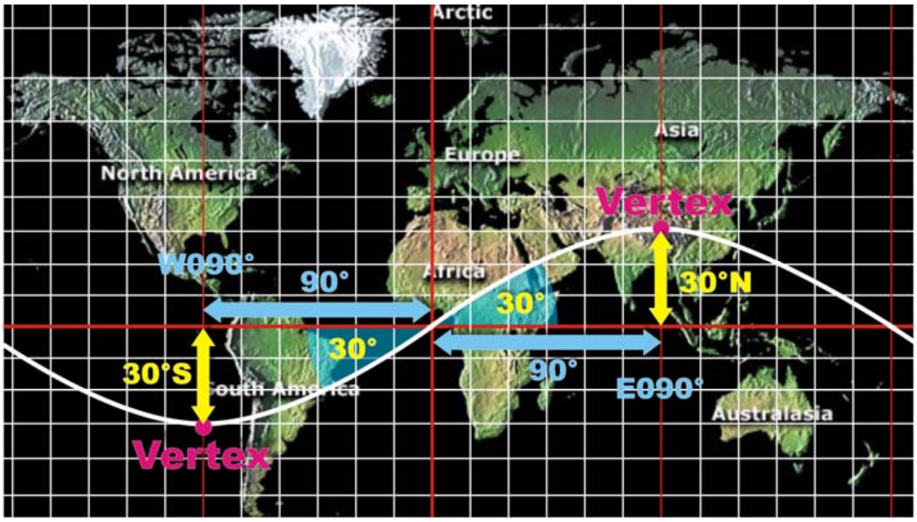
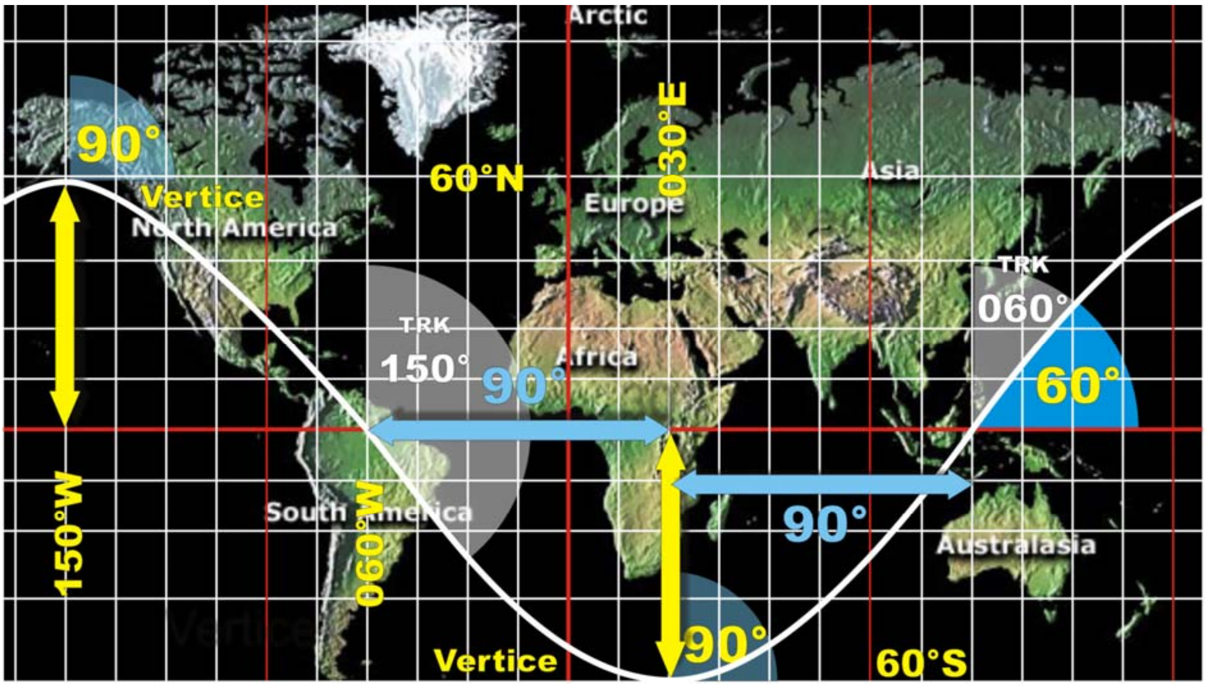
is always exactly 090°T or 270°T.

The vertices are always diametrically opposite each other, as are the points at which the great circle crosses the equator, and the vertices are always 90° in longitude removed from the equatorial crossing points.



Example:

Consider a great circle that crosses the Equator at longitude 120°E on a track of 030°T. Given no further information we deduce the following:



- The track angle is 030°T. Therefore, the track crosses the Equator at an angle of 60°, so the vertices are located at latitudes 60°N and 60°S respectively.

- The longitudes of the vertices are:

  at 60°N, 120°E + 90° = 150°W, and
  at 60°S, 120°E - 90° = 030°E

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- The other longitude at which the great circle crosses the equator is:
  120° E ± 180° = 60° W, and

  at that point, the track direction is 150°T,

- The track direction at 60°N 150°W and at 60°S 030°E, is 090°T.

These characteristics of the great circle lead to two properties that are of the utmost importance to the navigator:

- The shortest distance between any two points on the Earth's surface is the great circle track that joins them.

- Radio waves cross the Earth's surface along great circle tracks.

SHORTEST DISTANCE

The shortest distance between any two points is the straight line, but it is obviously impossible to draw a straight line around a spherical surface. Therefore, we must find the line of least curvature, i.e. the one that most closely approaches the straight line between the two points. The line of least curvature on the surface of a sphere is a line with radius of curvature equal to the radius of the sphere itself. A line of lesser radius would exhibit greater curvature, while a line of greater radius could not exist on the surface of that particular sphere. As we have seen, the radius of the great circle is equal to that of the Earth, and a unique great circle is defined between two given points. Therefore, the great circle track between two points provides the shortest distance between them.

RADIO WAVES

The path taken by radio waves over the Earth's surface is of importance in radio navigation.

Radio waves in free space travel in perfectly straight lines. The Earth's atmosphere causes some bending, but this is frequency - related and is negligible at the higher radio frequencies.

Consider an omni-directional antenna, i.e. one that transmits equally in all directions. The radio energy travels outwards from such an antenna as an expanding disc tangential to the Earth's surface at the antenna site, and hence perpendicular to the line joining the antenna with the centre of the Earth. Every element of the wavefront travels in a straight line, and therefore always lies in a plane that passes

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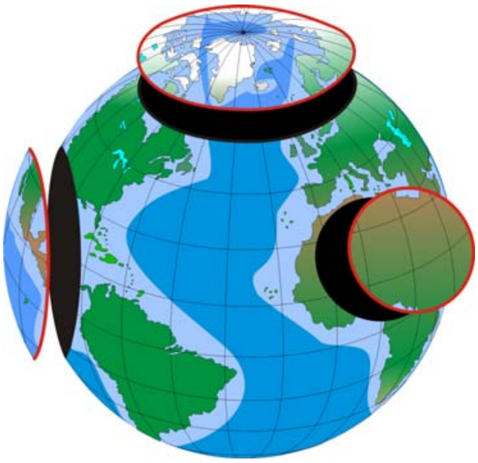
through the centre of the Earth. This is, of course, the plane of a great circle. As previously noted, an infinite number of great circles can be drawn through the transmitter site, and one such great circle defines the path from the transmitter to every other point reached by the radio wave.

At lower radio frequencies the wave is subjected to significant bending in the atmosphere and/or ionosphere, but as this bending occurs predominantly in the plane of the great circle it does not invalidate the reasoning outlined above.

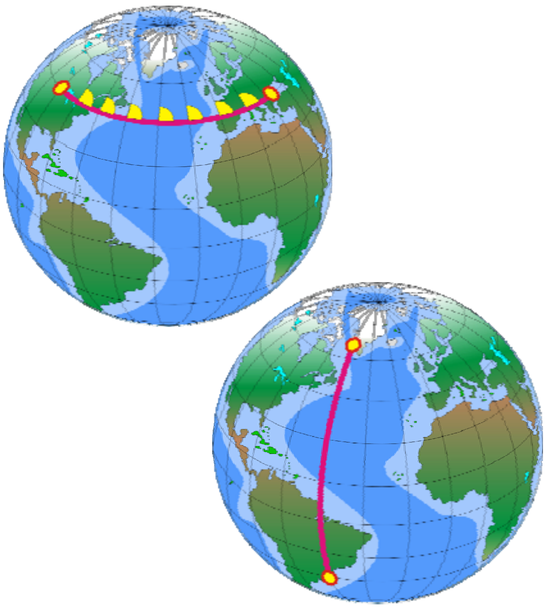
LINES ON THE EARTH -SMALL CIRCLES

A circle which does not pass through the centre of the sphere will divide the sphere unequally, and will intersect the surface along a line called a 'small circle'. Put another way, any circle on the Earth's surface that is not a great circle is a small circle. All the parallels of latitude except the Equator (a great circle), and the poles (dimensionless points) are small circles.



LINES ON THE EARTH - THE RHUMB LINE

The rhumb line is defined as that line between two points on the Earth's surface that cuts every meridian at the same angle. Therefore, by definition the rhumb line is a line of constant track angle, and this greatly simplifies the problem of navigation with a device like a magnetic compass. Like the great circle, the rhumb line is uniquely defined once the two end points have been specified.



The Equator and all the meridians are great circles, but they are also rhumb lines because they satisfy the additional definitional requirement for constant track direction. The other parallels of latitude are small circles and rhumb lines because they, too, define constant directions of 090T and 270T.

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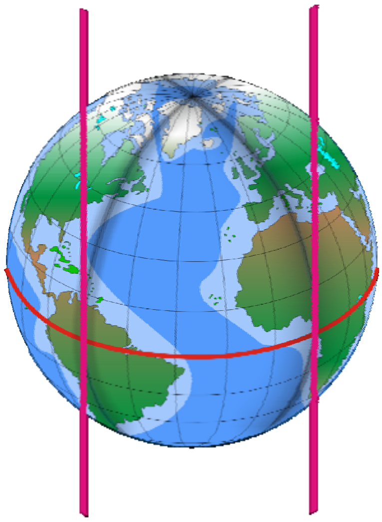
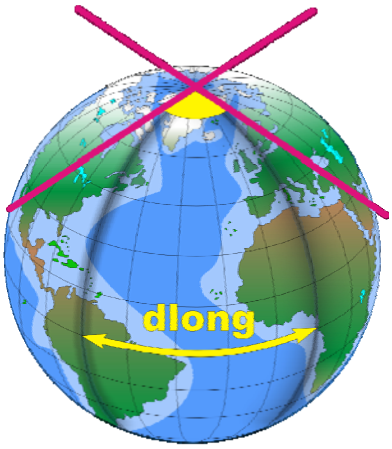
In general, however, rhumb lines do not lie within flat planes like great circles and small circles. Consider, for instance, a rhumb line track of 080°T commencing at a point on the Equator. Inspection of a globe will soon reveal that such a track will spiral towards the north pole, getting closer and closer but never actually reaching it. This is called a loxodromic spiral, and is characteristic of all rhumb lines except those on the cardinal directions 000°, 090°, 180° and 270°, which lie wholly within flat planes.

CONVERGENCY

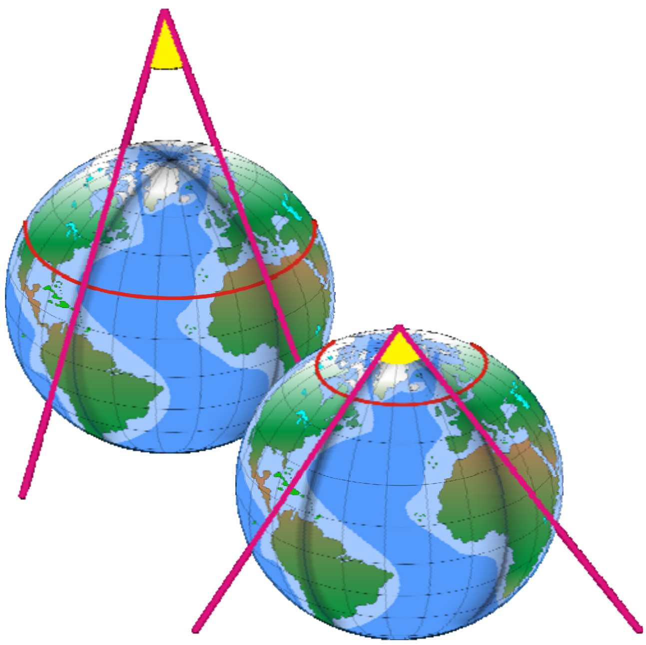
We have noted that all meridians cross the Equator at right angles. Since the equator lies on a flat plane passing through the centre of the Earth and is perpendicular to its spin axis, it follows that all meridians are parallel with the spin axis, and hence, with each other, as they cross the Equator.





At the pole, the meridians meet at a point, and the angle between them is the angle between their respective planes, i.e. the difference between their individual values of longitude. Hence, near the north pole, the direction of true north defined by the Greenwich meridian will differ from the direction of true north defined by, say, the 150°E meridian, by 150 degrees.

At any other latitude between the equator and pole there will be an angle of inclination between selected meridians which increases towards the poles. This angle of inclination between selected meridians at a particular latitude is known variously as Earth convergence, true convergence, meridian convergence or convergency.



The inclination between the meridians is directly proportional to the d long between them and increases from 0° at the equator to a maximum at the pole. The rate of change in inclination can be calculated

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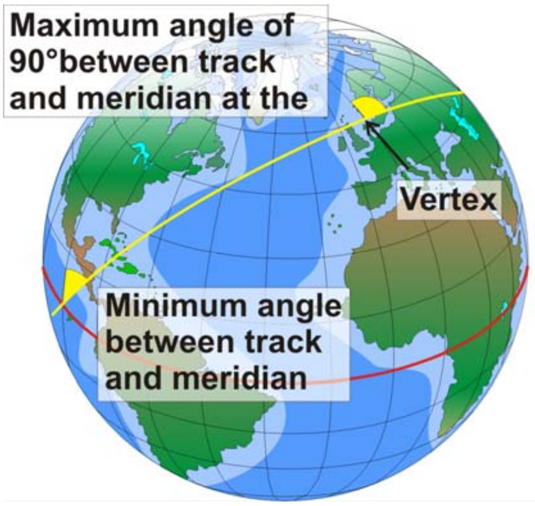
using the sin function.
Convergency can thus be calculated using the following formula:

C = d long x sin mean latitude

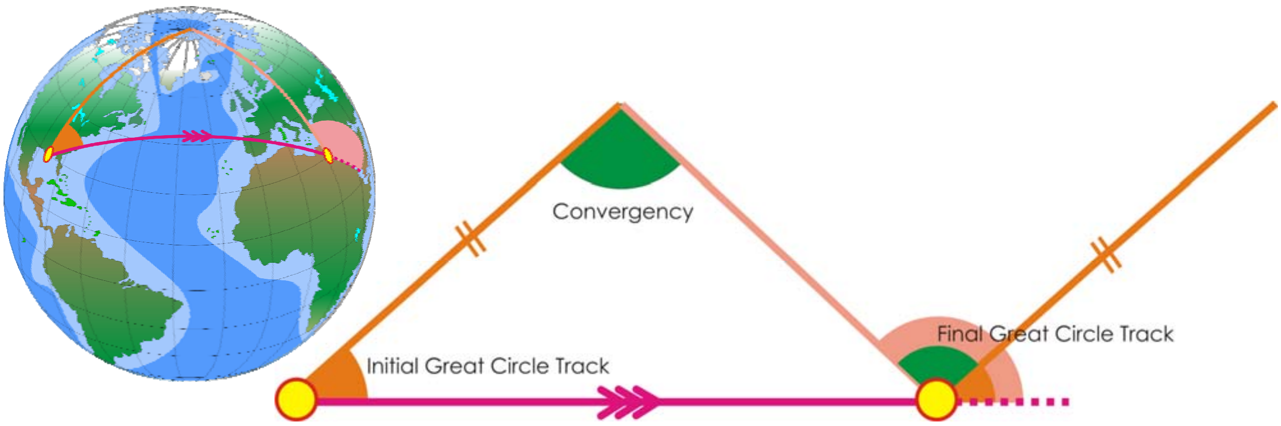
This is strictly correct only if the two places are on the same parallel of latitude, and if the d long is not excessive. If latitude also changes, sufficient accuracy for practical purposes is usually attainable by taking the latitude to be the mid-latitude between the two points. However, if greater precision is required, or if the situation involves a very large d long, the problem can only be solved by spherical trigonometry. Note in particular that the convergency between any two points separated by 180° d long is always 180°.

CONVERGENCY AND THE GREAT CIRCLE



The great circle provides another approach to the concept of convergency. Except in the special cases of the Equator and meridians, a great circle will cut all the meridians at different angles, varying from a minimum value at the equatorial points to a maximum of 90° at the vertices. But all great circles lie in flat planes that pass through the centre of the Earth, so the difference in great circle track direction between two points is a direct measurement of convergency between those points.

Using a plain triangle as a simplified version of the great circle track between two points, the relationship between the initial and the final great circle track angle is clearly equal to the convergency between the initial and final meridians.



A simple diagram is always helpful in determining whether the change in track direction is positive or negative. Using this concept of change of great circle track direction, it is obvious that the convergency between points separated by 180° d long is 180°, as previously mentioned.

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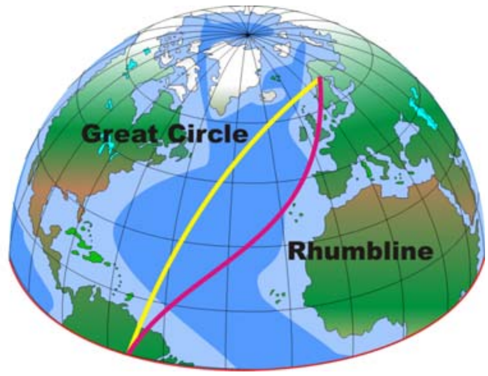
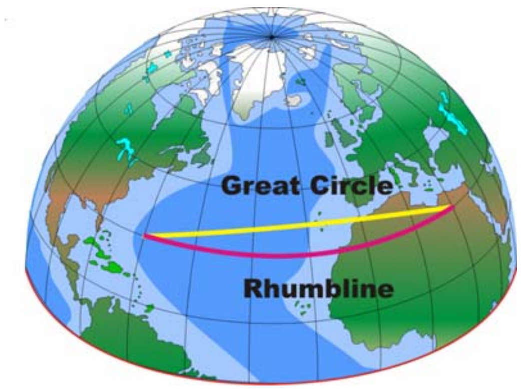
CONVERSION ANGLE

We stated previously that radio waves travel over the earth's surface along great circle tracks, while our primary mode of navigation is frequently along a rhumb line. For this and other reasons we need a simple means of determining the angular difference between the great circle and the rhumb line joining any given points.



First, we state a general qualitative rule of the utmost importance

'The rhumb line <u>always</u> lies closer to the equator than the great circle that joins the same two points'



No general proof of this rule will be offered. However, its truth can easily be verified in the special case of rhumb lines that are also parallels of latitude. Here it is evident that the plane of the great circle passing through the earth's centre will always project to the polar side of the plane of the small circle containing the rhumb line.

Having established the direction of the difference between the rhumb line and the great circle, we proceed to find the magnitude of the angle between them. This angle is called the 'conversion angle' (c.a.), and is determined thus:

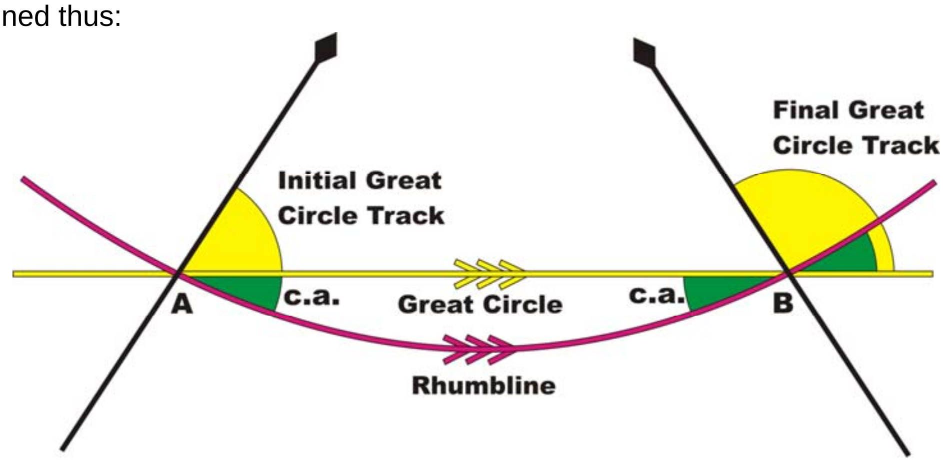


Figure 5

Consider two points, A and B, and the rhumb line and great circle tracks between them, as shown in Figure 5.

By definition RL track at A = RL track at B

∴ Initial GC track + c.a = Final GC track - c.a

∴ 2 c.a = Convergency

∴ c.a = ½ Convergency

∴ c.a = ½ d long x Sin mean lat

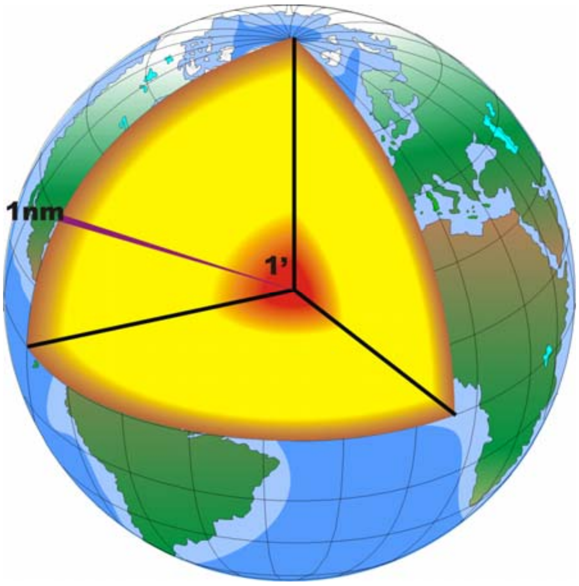
This derivation is only completely accurate if the two positions A and B are at the same latitude, and if d long is not too large. However, over distances of practical significance, adequate results are obtained if we put latitude equal to the value of the mid-latitude between the two points.

From Figure 5 we also observe that the greatest angular difference between the rhumb line and great circle is the conversion angle, and that this difference occurs at the extremities of the track. At or near the mid meridian between the two points, the rhumb line parallels the great circle. This fact is of practical significance in the actual measurement of tracks on a map.

DISTANCE

THE NAUTICAL MILE

The concept of latitude also gives rise to a convenient unit of length with which we can measure the distance between any two points on the Earth's surface. We have already noticed that latitude is defined in terms of an angle subtended by an arc of the local meridian. One 'nautical mile' (nm) is defined as that distance around the arc that subtends an angle of one minute at the Earth's centre. Noting that the 90° of latitude between the equator and the pole equals:



90 x 60 = 5 400 minutes,

we observe that the distance along a meridian from the equator to the pole is 5 400 nm.

Hence, the Earth's circumference is 21 600 nm, and its radius = $\frac{21600}{2\pi}$ = 3 438 nm

Because the nautical mile is aligned so closely with the dimensions of the Earth it is the 'natural' unit of distance to use for navigational purposes, and has been accepted by the International Committee of Weights and Measures 'for temporary use' with the SI system. For this purpose it is defined as 1852 metres (exactly) or 6076.12 feet, and this is sufficiently precise for most purposes.

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The magnitude of 1nm in everyday units is accepted by ICAO to be 1852 metres exactly, or about 6076 feet. These are, however, mean values. Because the Earth is not a perfect sphere, distances on the surface that subtend angles of 1 minute of arc at the centre will vary slightly with changing position and aircraft height. This variation must be considered in the design of the most accurate navigation systems but, for normal use, the mean values given above offer adequate precision.

THE KILOMETER

The metre was originally defined as 1/10,000,000 distance from equator to pole. One kilometre is 1000 metres, so the equatorial/polar distance is 10,000 km. Since the same distance is 5400 nm, we observe that:

$$54 \text{ nm} = 100 \text{ km and}$$

$$1 \text{ km} \approx 3280 \text{ feet}$$

In Australia the kilometre has almost completely replaced the statute mile as the standard 'large' unit of length for everyday use, but the statute mile is still widely used, especially in the US.

THE STATUTE MILE

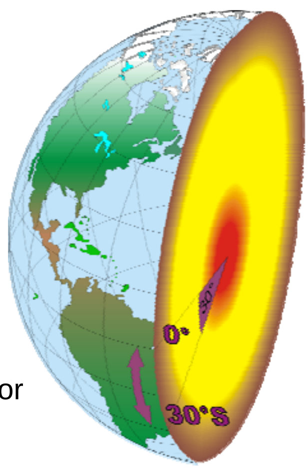
This is an arbitrary unit introduced by Queen Elizabeth I by Royal Statute, hence the name. The statute mile is defined as 5280 feet, or 1760 yards. Note that;

$$1 \text{ nm} = \frac{6076}{5280} = 1.15 \text{ statute miles, and}$$

$$1 \text{ nm} = \frac{6076}{3280} = 1.85 \text{ kilometres,}$$

both of which can be verified easily from the nautical/statute/km conversions on the Jeppesen computer.

DISTANCE VERSUS D LAT



The difference in latitude between any two points is normally expressed as the shortest arc of along a meridian. As seen before, all Meridians are segments of Great Circles and therefore 1 minute of d lat is equal to 1 nm.

As an example consider a point on the equator and a second point at 30°South. The d lat between the two points is 30°, or 1800 minutes of arc, which equates to 1800nm.

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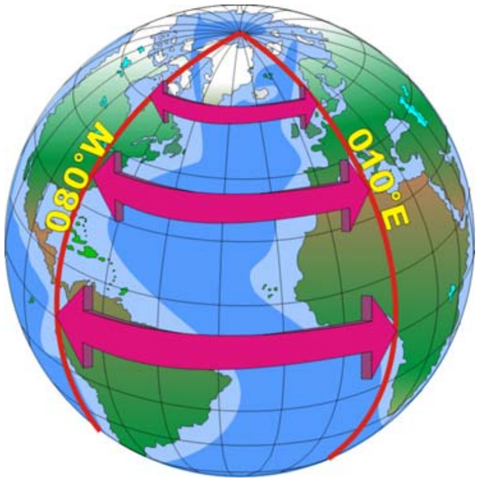
DEPARTURE



Minutes of longitude measured along parallels of latitude other than the Equator are not equivalent to nautical miles. Hence, we need to determine the relationship between minutes of longitude and distance or, more particularly, between d long and the nautical mile.

The distance between two given meridians, measured along a stated parallel and expressed in nautical miles, is called departure. In general terms it is defined as the East-West component of the rhumb line distance between two points. The value of departure between two meridians varies with latitude, decreasing with increasing latitude. The change of longitude between these meridians of course remains the same, irrespective of the latitude.

The departure distance between any two points is thus a function of their d long and their latitude and the relationship is given by:

Departure = d long (in minutes) x cos mean latitude

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