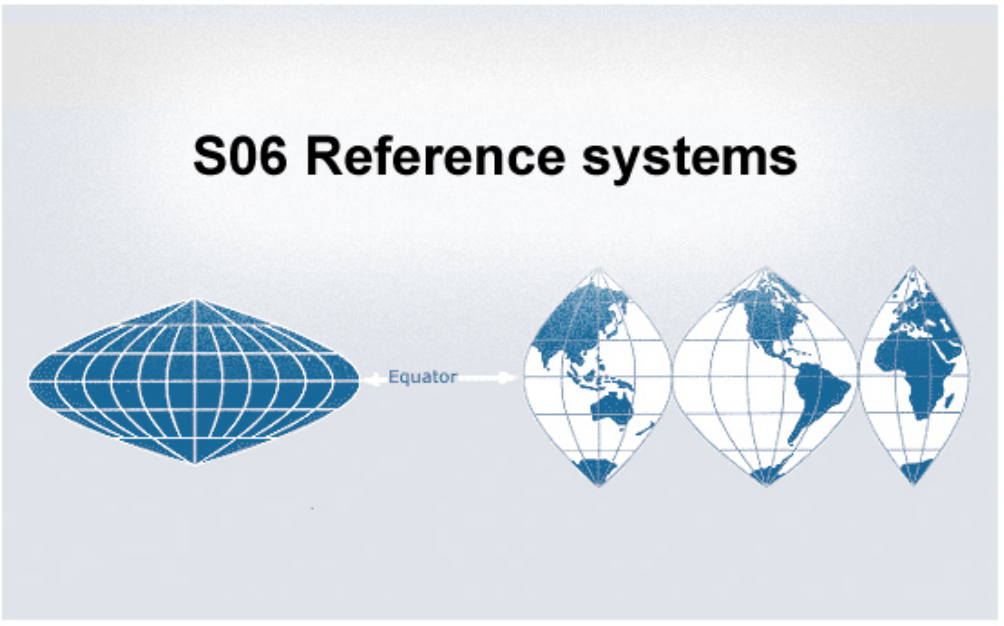
next>



Home
|
Self study
:
Reference sytems
|
Contents
|
Intro
|
1.Graticule / topographic grid
|
2.Projection Systems (a/b/c/d)
|
3.Plane rectangular coordinate systems (a/b)
|
4.Coordinate transfor-mations
|
5.Satellite-based positioning (a/b)

next>

TABLE OF CONTENTS

This module, about reference systems, is based on teaching materials prepared by Naftali Kadmon and Richard Knippers and a website, developed by the latter on Geometric aspects of mapping (ITC - Twente Technical University). These teaching materials are made available in the "documents" section. Our credits go out to Richard Knippers for putting so much material at our disposal.

The module contains the following chapters:

When reading through the following pages, you will come across some unusual terms. These terms are hyperlinked to the UNGEGN Glossary of Terminology (pdf). Behind each term a number (#) is given that corresponds to the numbering applied in this glossary, e.g. toponymy (#344).

For exercises and documents (and literature) on this topic see respectively the "Exercises" and/or the "Documents" section of this module.

The complete module can be downloaded here.

Home
|
Self study
:
Reference sytems
|
Contents
|
Intro
|
1.Graticule / topographic grid
|
2.Projection Systems (a/b/c/d)
|
3.Plane rectangular coordinate systems (a/b)
|
4.Coordinate transfor-mations
|
5.Satellite-based positioning (a/b)

INTRODUCTION

<previous - next>

It may be assumed that when man First began not only to relate to particular geographical objects in his environment but to convey their location to others of his species, he used verbal descriptions of the properties of the object in question, as well as physically pointing out their direct relation to the speaker.

An indication of distance must have come at a later stage. As was pointed out already in the introductory paper to this course (see Introduction to Toponymy), giving names to objects, must have been one of the earliest intellectual activities of the human race. However, before an object can be named it must be identified.

In the case of living things, which are mobile rather than fixed to a particular location, this usually involves relating to the properties of the subject. Identifying immovable objects, must involve a definition of location - otherwise there would be no possibility of distinguishing between them. This is particularly true of topographic features which make up categories or feature classes: mountains, rivers, lakes, islands and many others. In this lecture we shall briefly investigate how the location of geographical features - which are the objects of toponymy - can be defined.

Location can be defined on three main scales:

1. nominal - verbal description of location, i.e. by a name
2. ordinal - a named or numbered grid square forms a ordinal definition
3. quantitative - a location defined by its coordinates (geographic/cartesian coordinates.

In this module the focus is on the quantative scale.

<previous - next>

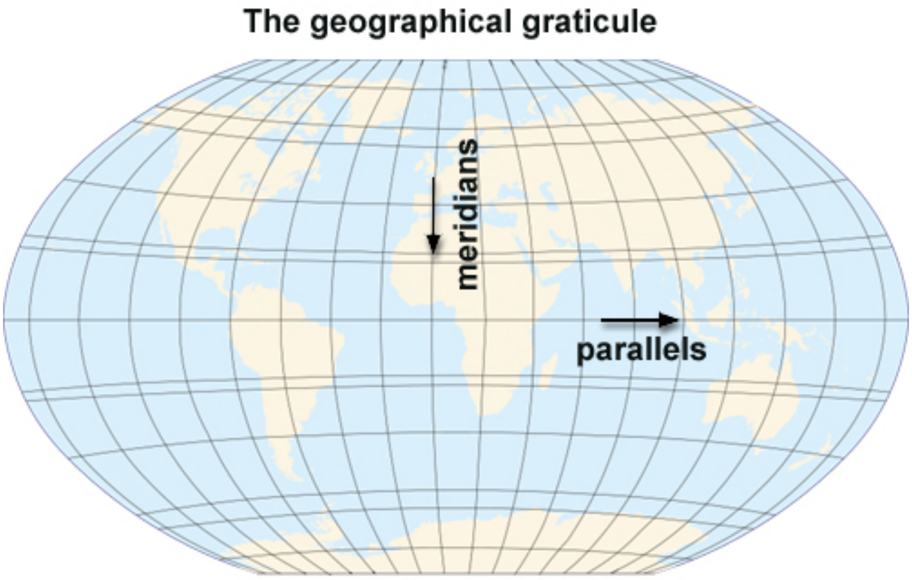
1. THE GEOGRAPHICAL GRATICULE AND TOPOGRAPHIC GRID

<previous - next>

Home
|
Self study
:
Reference sytems
|
Contents
|
Intro
|
1.Graticule / topographic grid
|
2.Projection Systems (a/b/c/d)
|
3.Plane rectangular coordinate systems (a/b)
|
4.Coordinate transfor-mations
|
5.Satellite-based positioning (a/b)

Geographical coordinates seem to be the most ancient quantitative method of defining locations. The earliest list of geographical names complete with quantitative locators is *Ptolemy's "Geographia"* of the 2nd century AD, which records some 8000 places by their names and their geographical coordinates.

The net of lines of latitude on the globe, also called parallels (because their planes are parallel to that of the equator), and of lines of longitude or meridians (which are half "great circles" extending from pole to pole), is called the geographical graticule.



Latitude of a place on the globe, is measured north or south from the equator as angles, in degrees, minutes and seconds. Longitude is similarly measured as an angle east or west from the prime meridian of Greenwich, England. These measurements thus constitute a precise quantitative system.

It is sometimes convenient to deal with only a limited portion of the Earth's surface and regard this not as curved but as a plane. This is what every conventional topographic map enables one to do, and the method of transferring places from the spherical surface of the Earth to the plane map sheet is called a ***cartographic projection***.

Since the representations of the lines of the graticule in a plane map are curved (except in the so-called cylindrical normal projections), and therefore inconvenient for measuring coordinate values from them, it is common practice to superimpose a plane rectangular net of squares on the map, of the well-known type called ***Cartesian coordinates***, and this is called a ***topographic*** or ***local grid***, or, if it covers a national territory, a ***national grid***, the coordinates then being called national coordinates. Such a grid is always based on a particular cartographic projection and it has a point of origin from which the coordinate values are measured.

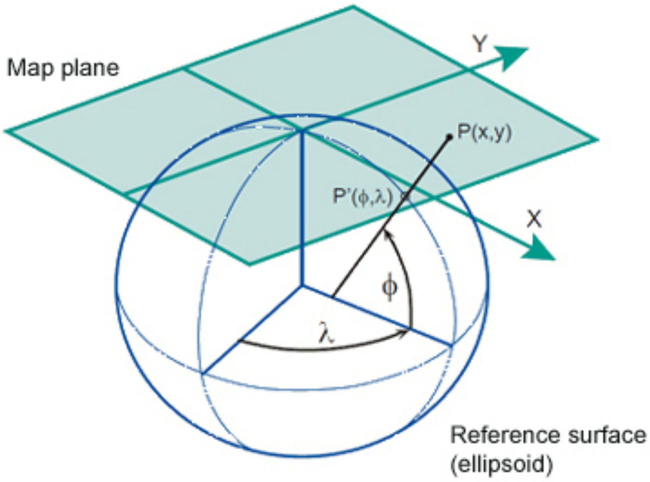
<previous - next>

2. PROJECTION SYSTEMS

<previous - next>

This chapter on projections systems is an extract from the website on "Geometric Aspects of mapping", ITC).

As mentioned, geographical (φ, λ) or rectangular coordinates (x, y) can be used to locate geographic features. Each feature with geographical coordinates on the reference surface of the Earth may be transformed to rectangular coordinates (x,y) representing positions on the map plane (see figure below).



Source: Geometric aspects of mapping, ITC

In other words, each feature may be transferred from the curved surface of the earth, approximated by a reference surface, to the flat plane of the map by means of a ***map projection***

A map projection therefore, is a mathematically described technique of how to represent the Earth’s curved surface on a flat map. To represent parts of the surface of the Earth on a flat paper map or on a computer screen, the curved horizontal reference surface must be mapped onto the 2D mapping plane. The reference surface for large-scale mapping is usually an oblate ellipsoid, and for small-scale mapping, a sphere.

Four aspects to take into consideration when choosing an appropriate map projection:

A) Classification of map projections
B) Scale distortions
C) Choosing a map projection
D) Commonly used map projections

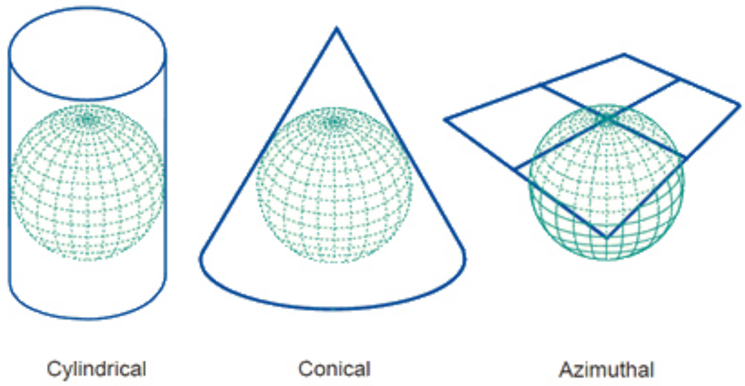
Each of the above aspects are explained in the following pages.

<previous - next>

Map projections can be described in terms of their:

1. ***class*** (cylindrical, conical or azimuthal),
2. point of ***secancy*** (tangent or secant),
3. ***aspect*** (normal, transverse or oblique), and
4. distortion ***property*** (equivalent or equidistant or conformal or another property, or no propery).

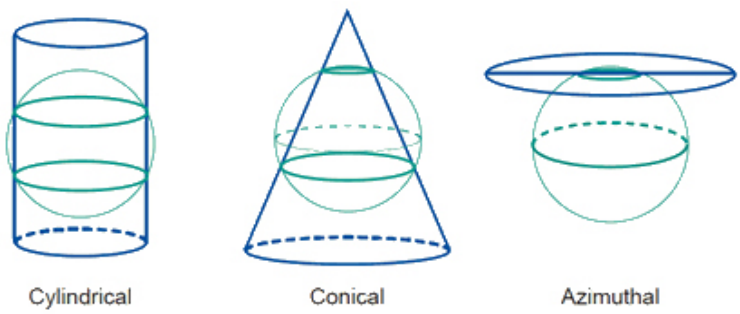
Ad 1) The three classes of map projections: cylindrical, conical and azimuthal. The projection planes are respectively a cylinder, cone and plane.



Source: Geometric aspects of mapping, ITC

The Earth's reference surface projected on a map wrapped around the globe as a cylinder produces a cylindrical map projection. Projected on a map formed into a cone gives a conical map projection. When projected directly onto the mapping plane it produces an azimuthal (or zenithal or planar) map projection. The figure above shows the surfaces involved in these three classes of projections.

Ad 2) In the figure above the surfaces are all tangent surfaces; they ***touch*** the horizontal reference surface in one point (plane) or along a closed line (cone and cylinder) only. But it is also possible that the surfaces ***intersect*** with (secant to) the horizontal reference surface (see image below). Then, the reference surface is intersected along one closed line (plane) or two closed lines (cone and cylinder). Secant map surfaces are used to reduce or average scale errors because the line(s) of intersection are not distorted on the map.

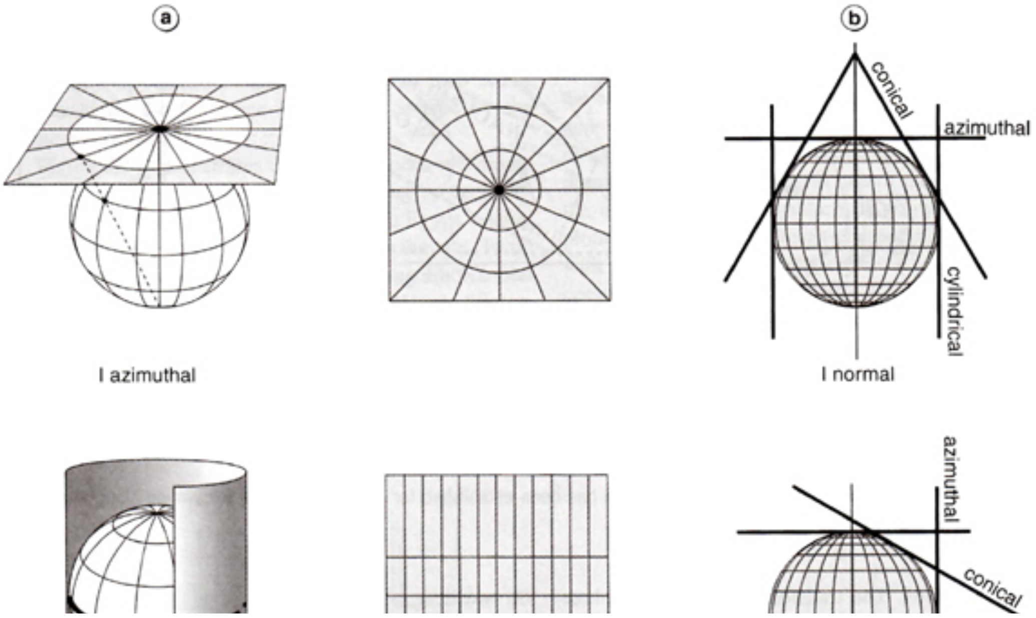


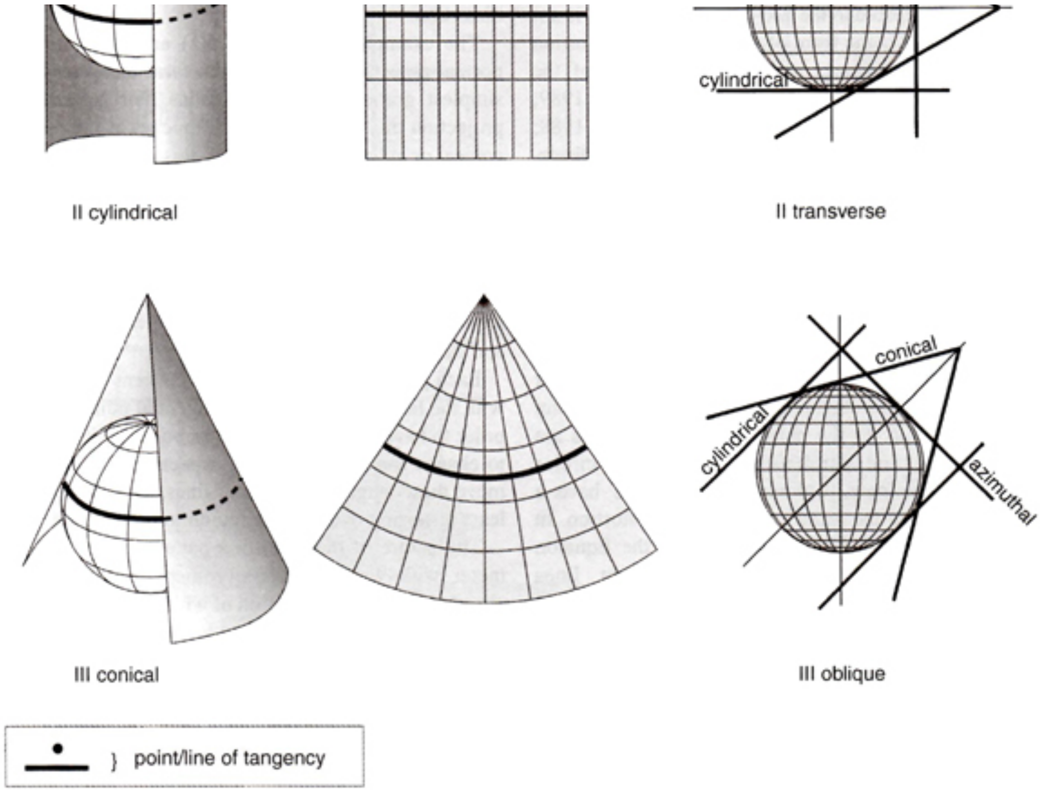
Source: Geometric aspects of mapping, ITC

Ad 3) The three possible apects are ***normal***, ***transverse*** and ***oblique***. In a normal projection, the main orientation of the projection surface is parallel to the Earth's axis (as in the figures above for the cylinder and the cone). A transverse projection has its main orientation perpendicular to the Earth's axis. Oblique projections are all other, non-parallel and non-perpendicular, cases.

Source: Geometric aspects of mapping, ITC

Image below from Kraak and Ormeling (2003/2010) summarizes it all.





Click here (or on image) for enlargement.

Ad 4) The distortion properties of a map are typically classified according to what is not distorted on the map:

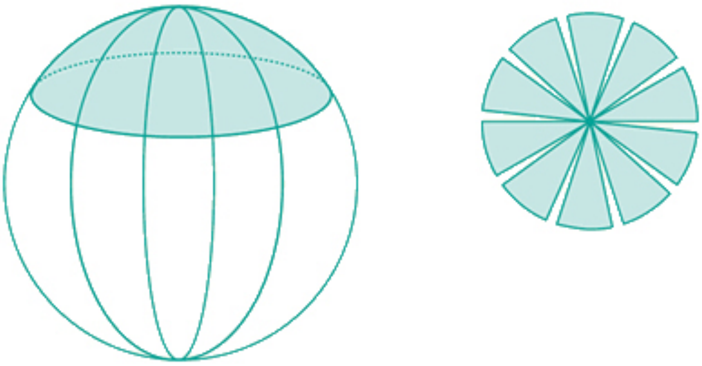
- In a ***conformal*** (***orthomorphic***) map projection the angles between lines in the map are indentical to the angles between the original lines on the curved reference surface. This means that angles (with short sides) and shapes (of small areas) are shown correctly on the map.
- In an ***equal-area*** (***equivalent***) map projection the areas in the map are identical to the areas on the curved reference surface (taking into account the map scale), which means that areas are represented correctly on the map.
- In an ***equidistant*** map projection the length of particular lines in the map are the same as the length of the original lines on the curved reference surface (taking into account the map scale).

A particular map projection may have any one of these three properties. No map projection can be both conformal and equal-area. A projection can only be equidistant (true to scale) at certain places or in certain directions. Other properties are for instance that great circles are always drawn as straight lines (in the conformal projection). Other projections present images that try to present an average between conformity and equal area.

2. PROJECTION SYSTEMS - *B) SCALE DISTORTIONS*

<previous - next>

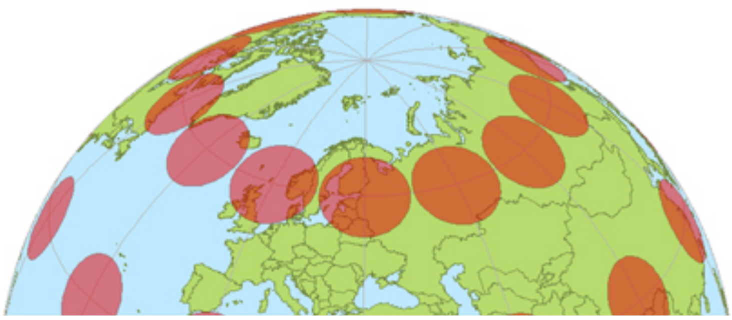
Unfortunately, any map projection is associated with scale distortions. There is no way to flatten out a piece of ellipsoidal or spherical surface without stretching some parts of the surface more than others (figure below). The amount and which kind of distortions a map will have depends largely - next to ***size of the area*** being mapped - on the ***type of the map projection*** that has been selected.

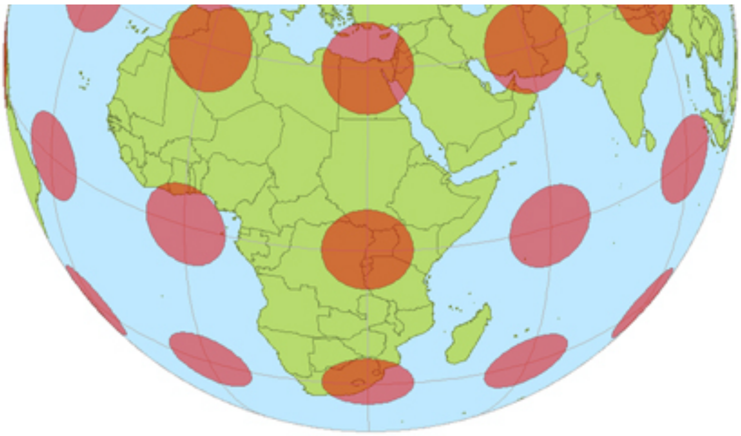


Source: Geometric aspects of mapping, ITC

Since there is no map projection that maintains correct scale all over the map, it may be important to know the extent to which the scale varies on a map. The map user therfore, should be aware of the distortions if he or she computes distances, areas or angles on the basis of measurements taken from these maps.

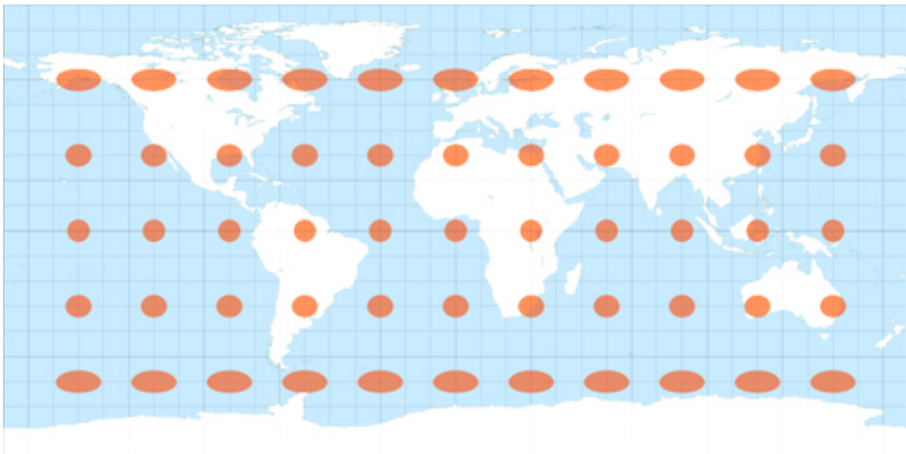
Scale distortions can be measured and shown on a map by ellipses of distortion. The ellipse of distortion, also known as ***Tissot's Indicatrix***, shows the shape of an infinite small circle with a fixed scale on the Earth as it appears when plotted on the map.





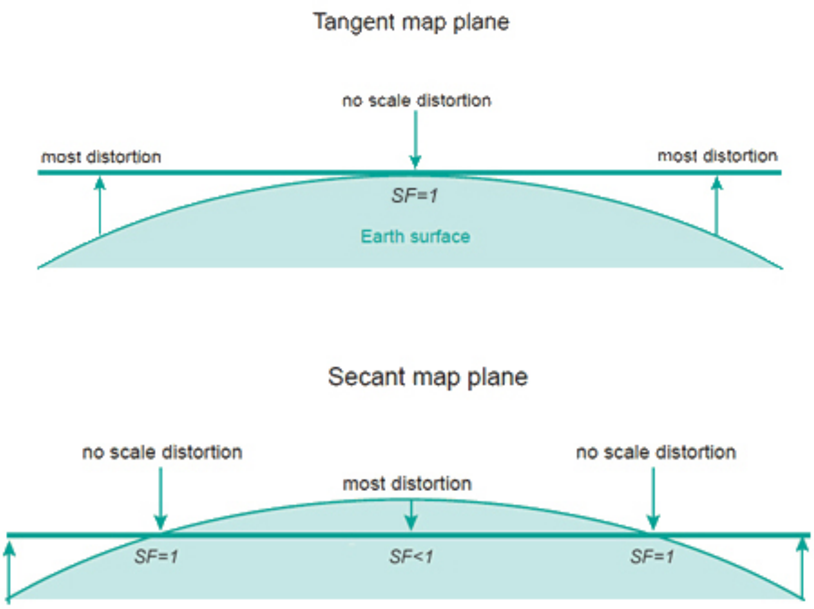
Source: Wikipedia / Author: Stephan Kühn - GNU Free Documentation License - Creative Commons Licenses

The indicatrices on the map in the figure below have a varying degrees of flattening, and the areas of the indicatrices on the map are not the same, which means that the distortion property of the map projection is therefore equidistant.



Source: Wikipedia / Author: Eric Gaba - GNU Free Documentation License - Creative Commons Licenses

Scale distortions for both, tangent and secant map surfaces, are illustrated in the figures below. Distortions increase as the distance from the central point (tangent plane) or closed line(s) of intersection increases.



Source: Geometric aspects of mapping, ITC

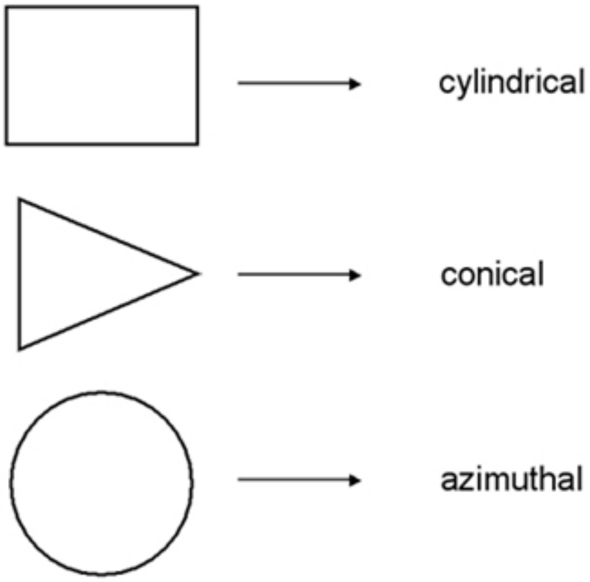
2. PROJECTION SYSTEMS - *C) CHOOSING A MAP PROJECTION*

<previous - next>

The cartographer's task is to ensure that the right type of projection is used for any particular map. A well chosen map projection takes care that scale distortions remain within certain limits and that map properties match to the purpose of the map. In theory, the selection of a map projection for a particular area can be made on the basis of:

1. the ***shape*** of the area,
2. the ***location*** (and orientation) of the area, and
3. the ***purpose*** of the map.

Ad 1) Ideally, the general ***shape*** of the mapping area should match with the distortion pattern of a specific projection (see figure below).



Ad 2) The choice of the aspect of a map projection depends largely on the location (and orientation) of the geographic area to be mapped. Optimal is when the ***projection centre*** coincides with centre of the area, or when the ***projection plane*** is located along the main axis of the area to be mapped.

Ad 3) Once the class and aspect of the map projection have been selected, the distortion property of the map projection has to be chosen. The most appropriate type of distortion property for a map depends largely on the purpose for which it will be used.

Map projections with a ***conformal distortion property*** represent angles and local shapes correctly, but as the region becomes larger, they show considerable area distortions. An example is the Mercator projection. Although Greenland is only one-eighth the size of South America, Greenland appears to be larger on the Mercator projection. Maps used for the measurement of angles (e.g. aeronautical charts, topographic maps) often make use of a conformal map projection.

Map projections with a ***equal-area distortion property*** on the other hand, represent areas correctly, but as the region becomes larger, it shows considerable distortions of angles and consequently shapes. Maps which are to be used for measuring areas (e.g. distribution maps) often make use of an equal-area map projection.

The ***equidistant distortion property*** is achievable only to a limited degree. That is, true distances can be shown only from one or two points to any other point on the map or in certain directions. If a map is true to scale along the meridians (i.e. no distortion in North-South direction) we say that the map is equidistant along the meridians (e.g. the equidistant cylindrical projection in the figure below). If a map is true to scale along all parallels we say the map is equidistant along the parallels (i.e. no distortion in East-West direction). Maps which require correct distances measured from the centre of the map to any point (e.g. air-route, radio or seismic maps) or maps which require reasonable area and angle distortions (several thematic maps) often make use of an equidistant map projection

In summary, the ideal map projection for any country would either be an azimuthal, cylindrical, or conic projection, depending on the shape of the area, with a secant projection plane located along the main axis of the country or the area of interest. The selected distortion property depends largely on the purpose of the map.

<previous - next>

2. PROJECTION SYSTEMS - *D) COMMONLY USED MAP PROJECTIONS*

The table below gives an overview of some commonly used projection systems, with an annotation that discusses their properties, as relevant for specific uses of these maps. The projections are categorized according to projection plane.

Projection	Remarks
Cylindrical	
Central cylindrical	Map is perspective but not conformal nor equal area. Projected perspectively from the center of the earth onto a cylinder tangent to the equator. Only used for teaching purposes.
Equidistant cylindrical	Also called Simple Cylindrical or Plate Carree. Used for raster maps which store information of the whole world: Each pixel represents a square block of LatLon coordinates, i.e. information is stored per degree, per minute, etc. Used for mapping the earth taken as a sphere.
EquiRectangular	Also called Plate Rectangle. Variant of Plate Carree. Used for raster maps which store information of the whole world: Each pixel represents a rectangular block of LatLong coordinates.
Mercator	Conformal. Designed for navigational use; standard for marine charts. Recommended use for conformal mapping of regions predominantly bordering the equator. Often inappropriately used as a world map.
Trasverse Mercator	Also called Gauss Conformal, or Gauss Krüger. Transverse form of the Mercator Projection (conformal). Used for many topographic maps at scales from 1: 20000 to 1: 250000. Recommended for mapping regions that are predominantly north-south in extent.
UTM	Universal Transverse Mercator. Map is conformal. Widely used for topographic maps and military maps.
Lambert Cylindrical Equal Are	Lambert Cylindrical Equal Area. Mainly used for educational purposes.
Mollweide	Pseudo-cylindrical projection. Map is equal area. Occasionally used in thematic world maps.
Azimuthal	
Lambert Azimuthal Equal Area	Lambert Azimuthal Equal Area. Used for maps of continents and hemispheres. Also suited for regions extending equally in all directions from a center point, such as Asia and the Pacific Ocean.
Azimuthal Equidistant	Azimuthal Equidistant. Commonly used in the polar aspect for maps of polar regions and the Northern and Southern hemispheres. The oblique aspect is frequently used for world maps centered on important cities and occasionally for maps of continents.
Orthographic	Known by Egyptians and Greeks 2000 years ago. Map is perspective and neither conformal nor equal area. Only one hemisphere can be shown. The earth appears as it would on a photograph from space.
Stereographic	Apparently invented by Hipparchus (2nd century BC). Used in combination with UTM projection as Universal Polar Stereographic (UPS) for mapping poles and in navigation charts for latitudes above 80°. Recommended for conformal mapping of regions that are approximately circular in shape. For example, used for topographic maps of the Netherlands.
Gnomonic	Map is perspective and neither conformal nor equal area. It is used to show great circle paths as straight lines and thus to assist navigators and aviators.
Conical	
Albers Equal Area Conic	If the pole is one of the standard parallels, it is equal to Lambert's Equal Area Conic. Frequently used for maps of the United States, for thematic maps and for world atlases. Recommended for equal area maps of regions that are mainly east-west in extent.
Lambert Conformal Conical	Lambert Conformal Conic/Conical Orthomorphic (Lambert, 1972) (conformal). Extensively used for large-scale mapping of regions predominantly east-west in extent. Further widely used for topographic maps.
Equidistant Conic	Also called Simple Conic. The most common projection in atlases for small countries.
Polyconic	or American Polyconic (Hassler, ± 1820). Map is neither conformal nor equal area. The sole projection used for large scale mapping of the United States by the USGS until the 1950's.

Source: Geometric aspects of mapping, ITC
(Click here for enlargement)

For more detailed information on projections see Chapter 4 of "Geometric aspects of mapping".

3. PLANE RECTANGULAR COORDINATE SYSTEMS

<previous - next>

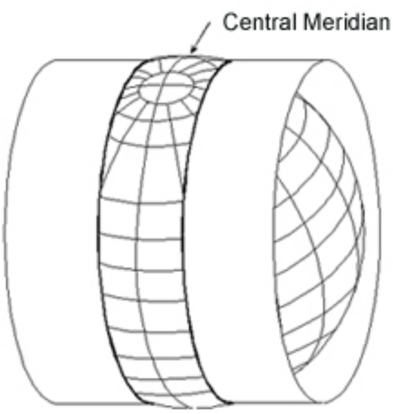
Rectangular coordinate systems for national use, also called national grid systems, are always based on a particular map projection.

A map projection by itself isn't enough to define a national grid system. One has to define e.g.:

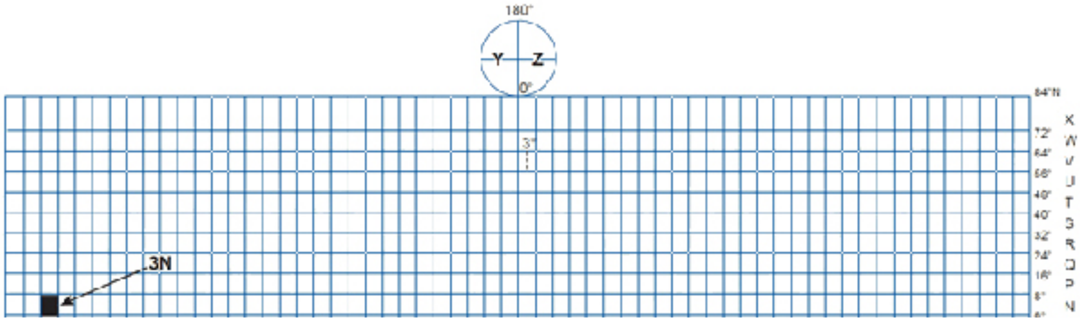
A) the ***ellipsoid*** / ***geoïd*** and
B) ***horizontal datum***,
C) the ***center*** of the projection,
D) the ***scale factor***,
E) and the ***origin*** of the rectangular coordinate system.
F) *False* ***Easting*** and False ***Northing***
G) ***Central Meridian*** (λ_0) or the standard parallels

The above points A) and B) are described in seperate paragraphs on the following pages.

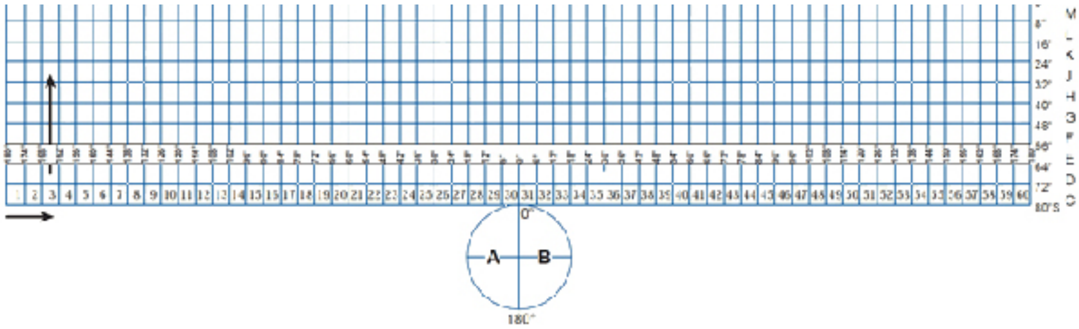
The most widely used grid system is the so-called UTM system. UTM stands for Universal Tranversal Mercator, this being the name of the cartographic projection on which it is based. The UTM system is designed to cover the whole world (excluding the Artic and Antartic regions). It is a version of the Transverse Mercator projection, see figure below.



The UTM grid too is a square kilometric grid. To keep scale distortians in acceptable limits, the grid is "cut up' into 60 zones with a width of 61 of longitude each, numbered from 1-60 in a west-east direction starting from the international date line (long. 1801) with zone 1.



Home
|
Self study
:
Reference sytems
|
Contents
|
Intro
|
1.Graticule / topographic grid
|
2.Projection Systems (a/b/c/d)
|
3.Plane rectangular coordinate systems (a/b)
|
4.Coordinate transfor-mations
|
5.Satellite-based positioning (a/b)



Click here for enlargement and original file (location / source).

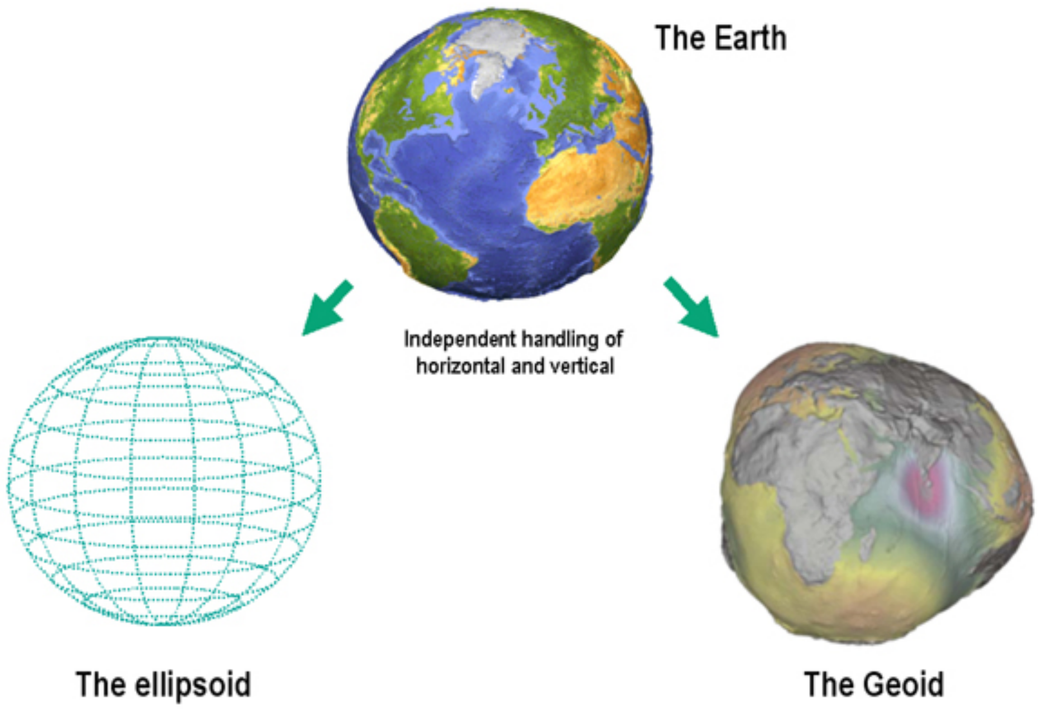
X-values, in km, are measured in the northern hemisphere northward from the equator, whose value again is 0 km; in the southern hemisphere kilometric measurements are, again, northwards but so that the equator is assigned the value of 10,000 km. Y-values are always measured in a west-east direction: the central meridian of each zone is assigned the value 500 km. This system ensures that there can be no negative UTM values and there never is a need for + or - signs, which is convenient.

3. PLANE RECTANGULAR COORDINATE SYSTEMS - *A) THE ELLIPSOID / GEOID*

<previous - next>

Home
|
Self study
:
Reference sytems
|
Contents
|
Intro
|
1.Graticule / topographic grid
|
2.Projection Systems (a/b/c/d)
|
3.Plane rectangular coordinate systems (a/b)
|
4.Coordinate transfor-mations
|
5.Satellite-based positioning (a/b)

Up till now we have regarded the Earth as a perfect sphere, but it is not. It is not only flattened on the poles, but its surface is also irregular, and that is why we call it a geoid. In order to represent it with the least possible distortion, we try to project this geoid on an ellipsoid that fits our area best. There are both geoids that fit a particular part of the world best and geoids that fit the geoid best globally. For GPS measurements we opt for a global system.

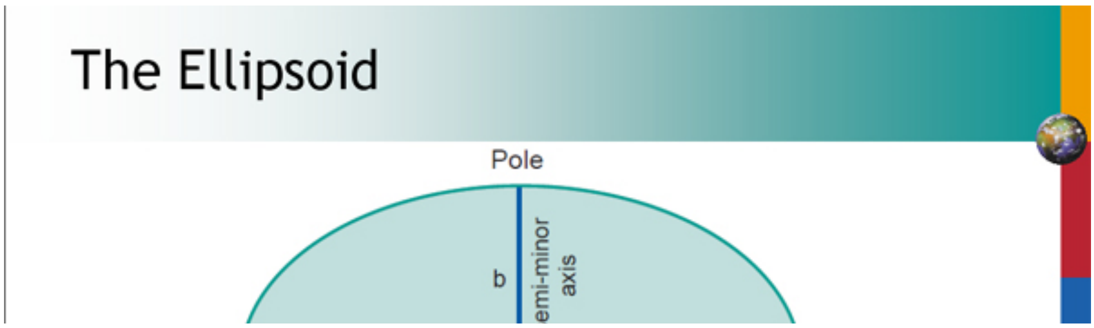


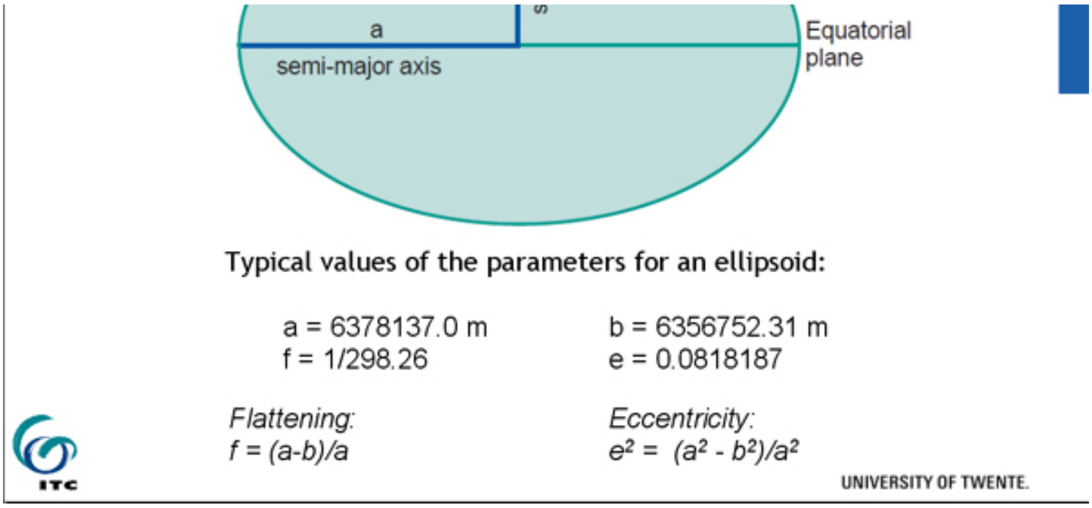
Source: Knippers, 2010

In words, Wiki defines an (reference) ellipsoid as:

> *"... a mathematically-defined surface that approximates the geoid, the truer figure of the Earth, or other planetary body. Because of their relative simplicity, reference ellipsoids are used as a preferred surface on which geodetic network computations are performed and point coordinates such as latitude, longitude, and elevation are defined.....*
>
> *...... Mathematically, a reference ellipsoid is usually an oblate (flattened) spheroid with two different axes: An equatorial radius (the semi-major axis a), and a polar radius (the semi-minor axis b)".*

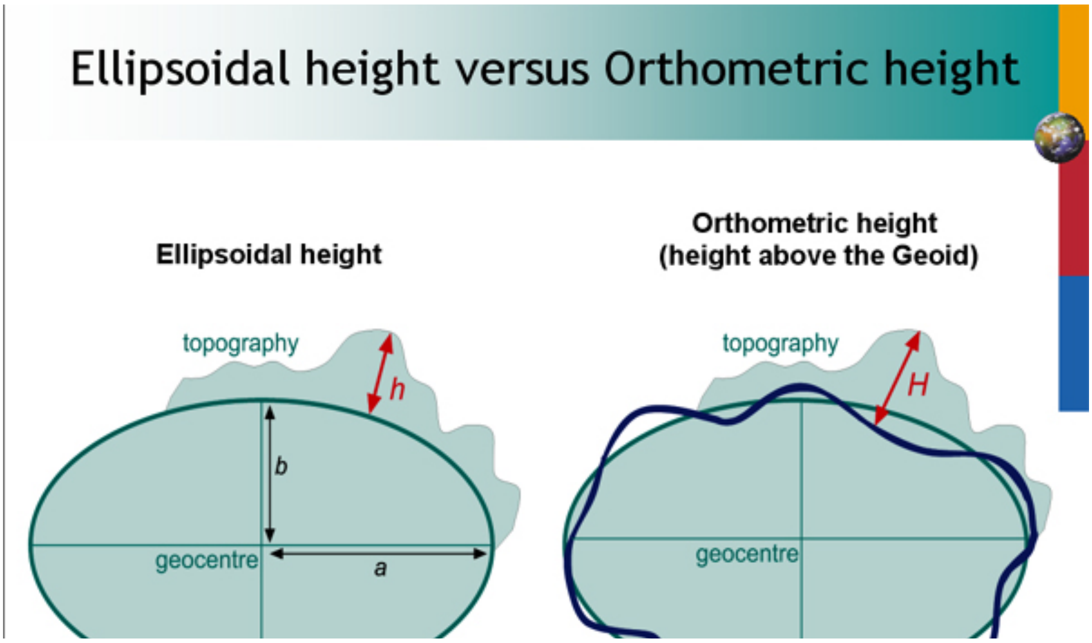
See image below for typical parameters for an ellipsoid.





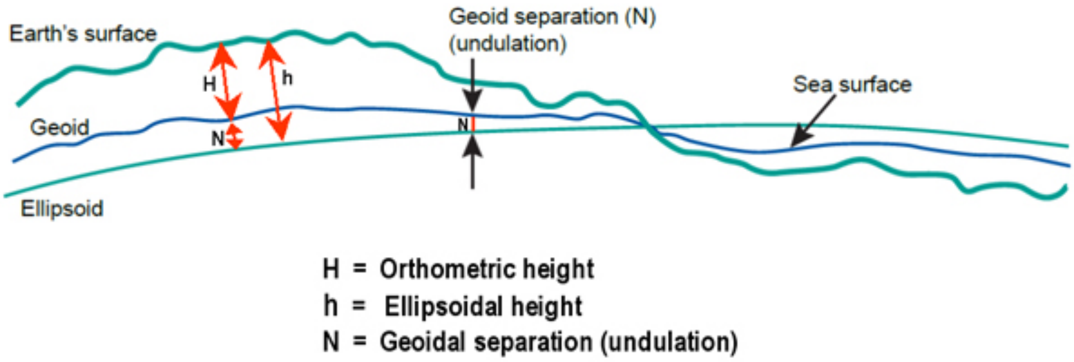
Source: Knippers, 2010

The Geoid is used to describe heights.



Source: Knippers, 2010

In order to establish the Geoid as reference for heights, the ocean's water level is registered at coastal places over several years using tide gauges (mareographs). Averaging the registrations largely eliminates variations of the sea level with time. The resulting water level represents an approximation to the Geoid and is called the mean sea level.

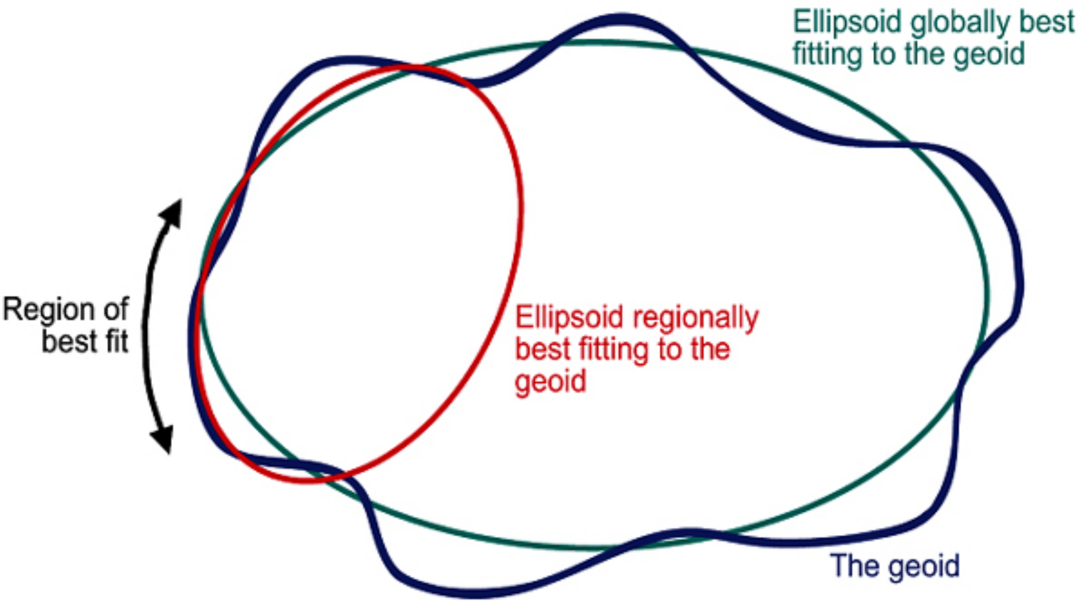


Source: Knippers, 2010

The geoidal undulation (N) is the separation between the geoid and an ellipsoid. It varies globally between ±110 m.

> There are also several realizations of ***local*** mean sea levels (also called ***local vertical datums***) in the world. They are parallel to the Geoid but offset by up to a couple of meters. This offset is due to local phenomena such as ocean currents, tides, coastal winds, water temperature and salinity at the location of the tide-gauge.Care must be taken when using heights from another local vertical datum. This might be the case in the border area of adjacent nations.

Countries establish a horizontal (or geodetic) datum (see next paragraph), which is an ellipsoid with a fixed position, so that the ellipsoid best fits the surface of the area of interest (the country)



Source: Knippers, 2002

Commonly used ellipsoids are:

Name	Date	a (m)	b (m)	Use
Everest	1830	6377276	6356079	India, Burma, Sri Lanka
Bessel	1841	6377397	6356079	Central Europe, Chile, Indonesia
Airy	1849	6377563	6356257	Great brittain
Clarke	1866	6378206	6356584	North America, Philippines
Clarke	1880	6378249	6356515	France, Africa (parts)
Helmert	1907	6378200	6256818	Africa (parts)
International (or Hayford)	1924	6378388	6356912	World
Krasovsky	1940	6378245	6356863	Russia, Eastern Europe
GRS80	1980	6378137	6356752	North America
WGS84	1984	6378137	6356752	World (GPS measurements)

In the next paragraph more information is given on geodetic datums.

3. PLANE RECTANGULAR COORDINATE SYSTEMS - *B) HORIZONTAL DATUMS*

<previous - next>

Home | Self study : Reference sytems | Contents | Intro | 1.Graticule / topographic grid | 2.Projection Systems (a/b/c/d) | 3.Plane rectangular coordinate systems (a/b) | 4.Coordinate transfor-mations | 5.Satellite-based positioning (a/b)

Ellipsoids have varying position and orientations. An ellipsoid is positioned and oriented with respect to the local mean sea level (or Geoid) by adopting a latitude (φ) and longitude (λ) and ellipsoidal height (h) of a so-called fundamental point and an azimuth to an additional point. We say that this defines a local horizontal datum. Notice that the term ***horizontal datum*** and ***geodetic datum*** are being treated as equivalent and interchangeable words. We make a distinction between ***local*** and ***global*** horizontal datums.

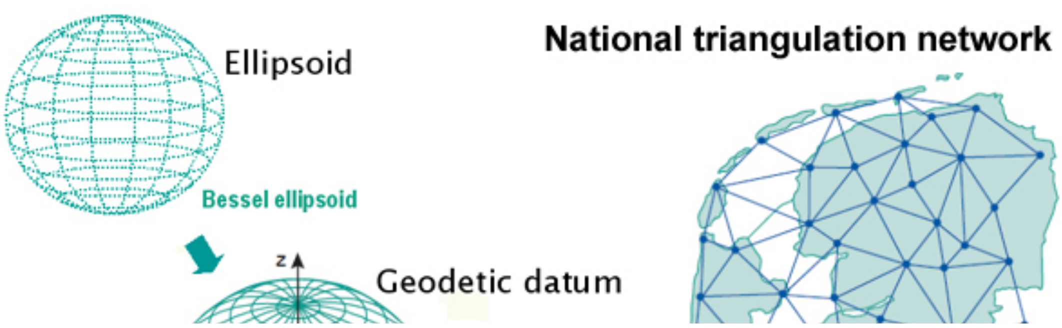
Several hundred local horizontal datums exist in the world. The reason is obvious: Different local ellipsoids with varying position and orientation had to be adopted to best fit the local mean sea level in different countries or regions.

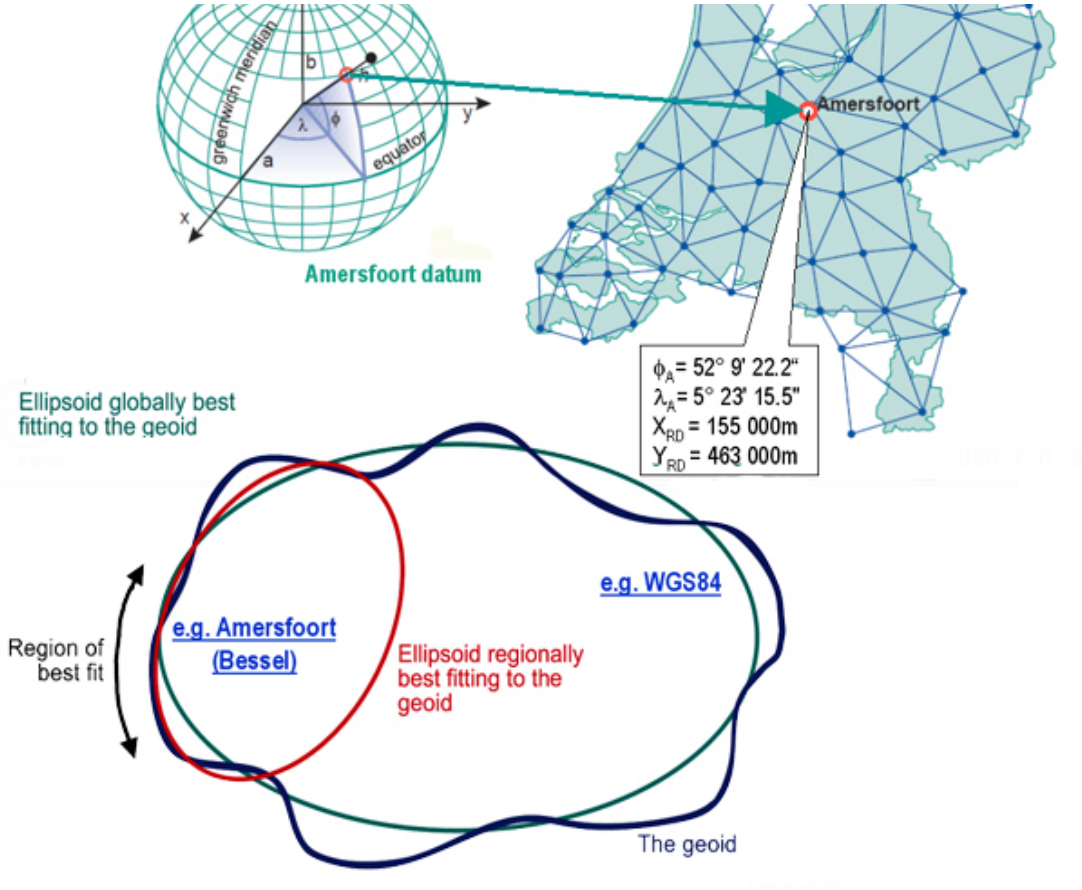
For examples of local horizontal datums with their underlying ellipsoid and difference in position (datum shift) with respect to ***WGS84,*** see image below.

Datum	Ellipsoid	Datum shift (m) (Dx, Dy, Dz)
Alaska (NAD-27)	Clarke 1866	-5, 135, 172
Bahamas (NAD-27)	Clarke 1866	-4, 154, 178
Bermuda 1957	Clarke 1866	-73, 213, 296
Central America (NAD-27)	Clarke 1866	0, 125, 194
Bellevue (IGN)	Hayford	-127, -769, 472
Campo Inchauspe	Hayford	-148, 136, 90
Hong Kong 1963	Hayford	-156, -271, -189
Iran	Hayford	-117, -132, -164

Source: Knippers, 2002

Below, the situation in the Netherlands.





Source: Knippers, 2010

In the above case, the local horizontal datum is realized through a so-called triangulation network (or survey network). Such a network consists of monumented points forming a network of triangular mesh element (figure below). The angles in each triangle are measured in addition to at least one side of a triangle; the fundamental point is also a point in the triangulation network. The angle measurements and the adopted coordinates of the fundamental point are then used to derive geographic (or geodetic) coordinates (φ, λ) for all monumented points of the triangulation network.

Global horizontal datums

With increasing demands for global surveying activities are underway to establish global reference surfaces. The motivation is to make geodetic results mutually comparable and to provide coherent results also to other disciplines like astronomy and geophysics.

The most important global (or geocentric) spatial reference system for the GIS community is the ***International Terrestrial Reference System*** (ITRS). It is a three-dimensional coordinate system with a well-defined origin (the centre of mass of the Earth) and three orthogonal coordinate axes (X,Y,Z). The Z-axis points towards a mean Earth north pole. The X-axis is oriented towards a mean Greenwich meridian and is orthogonal to the Z-axis. The Y-axis completes the righthanded reference coordinate system.

The ITRS is realized through the ***International Terrestrial Reference Frame*** (ITRF), a distributed set of ground control stations that measure their position continuously using GPS.

The trend is to use the ITRF everywhere in the world for reasons of global compatibility. The World Geodetic System of 1984 (WGS84) datum has been refined on several occasions and is now aligned with the ITRF to within a few centimetres worldwide. The Global Positioning System (GPS) uses the WGS84 as its reference system.

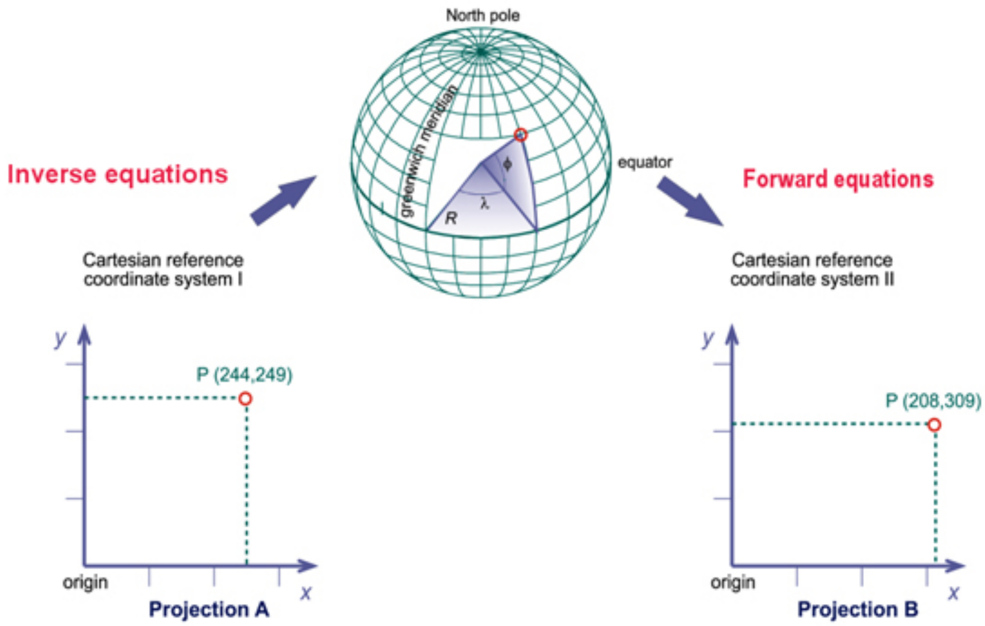
Global horizontal datums, such as the ITRF2000 or WGS84, are also called ***geocentric datums*** because they are geocentrically positioned with respect to the centre of mass of the Earth. They became available roughly after the 1960's, with advances in extra-terrestrial positioning techniques.

4. COORDINATE TRANSFORMATIONS

<previous - next>

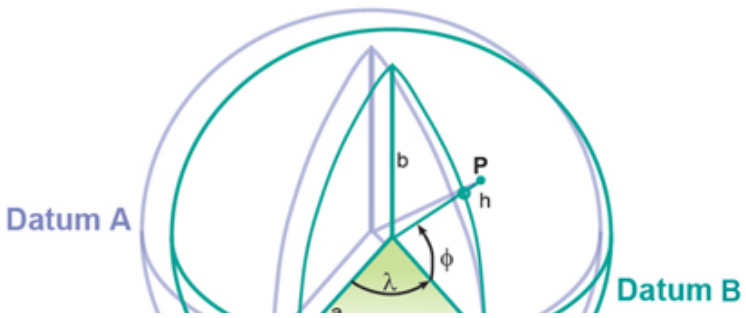
Co-ordinate transformations are used to bring spatial data into a common reference system. Most countries have defined their own common reference system. For example, spatial data that are related to the Universal Transverse Mercator projection system may need to be transformed to the Dutch RD system if this system is the reference system in use. This is done by converting the UTM coordinates First into geographical coordinates and then converting these geographical coordinates into coordinates of the Dutch RD system.

1. **Changing map projection**

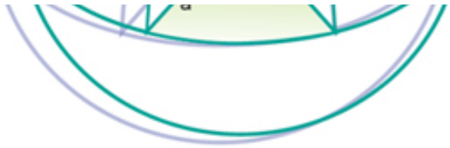


Source: Powerpoint presentation - Knippers, 2010

2. **Datum transformation**
   - via geocentric coordinates
   - via geographic coordinates



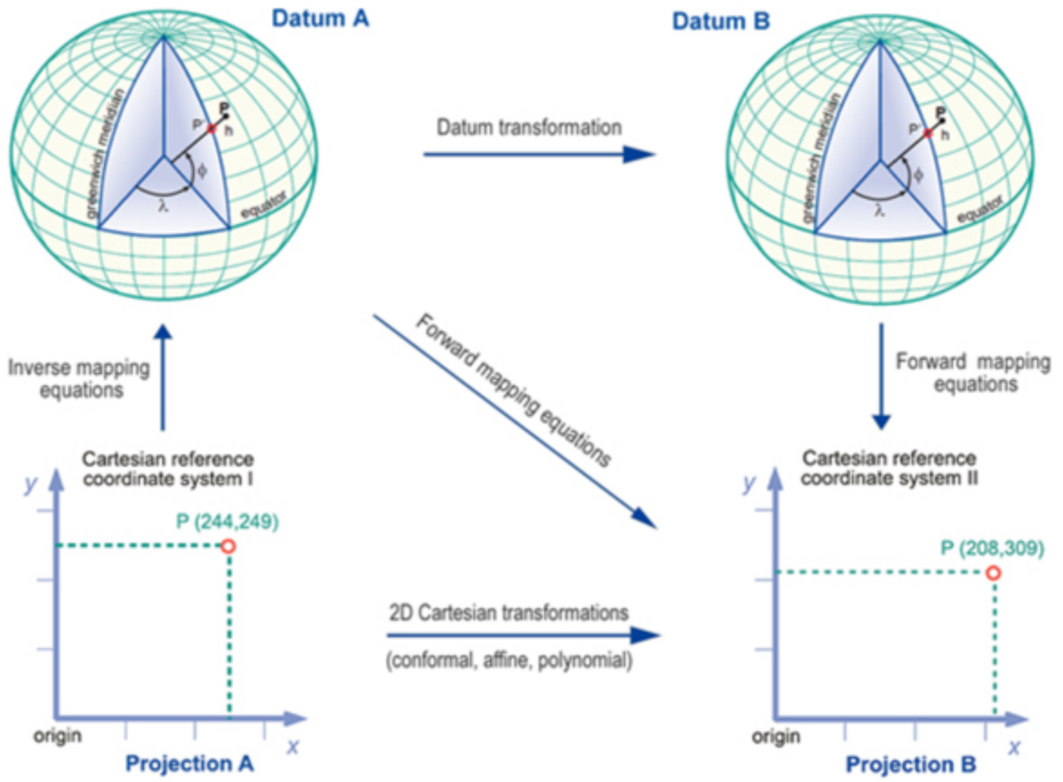
Home | Self study : Reference sytems | Contents | Intro | 1.Graticule / topographic grid | 2.Projection Systems (a/b/c/d) | 3.Plane rectangular coordinate systems (a/b) | 4.Coordinate transfor-mations | 5.Satellite-based positioning (a/b)



Source: Powerpoint presentation - Knippers, 2010

3. **Direct transformations**
   - conformal transformation,
   - affine transformation, and
   - polynomial transformation

An overview of coordinate transformations is given below.



Source: Powerpoint presentation - Knippers, 2010

For more information on this subject see:

- Chapter 5 "Coordinate transformation, on website "Geometric aspects of Mapping"
- Knippers, R.A and J. Hendrikse (2001). *Coordinate transformations*. Kartografisch Tijdschrift, KernKatern 2000-3 (URL / pdf).

5. SATELLITE-BASED POSITIONING

<previous - next>

A lot can be told about satellite-based positioning, in great detail and the techniques that go along with it. In this paragraph we will stick to the basics:

A) The segments of a satellite-based positioning system are:

1. Space segment
2. Control segment
3. User segment

B) Principles of positioning

1. Abosulte positioning
2. Relative positioning

Points A) and B) are explained in the next pages.

<previous - next>

5. SATELLITE-BASED POSITIONING - *A) SEGMENTS*

<previous - next>

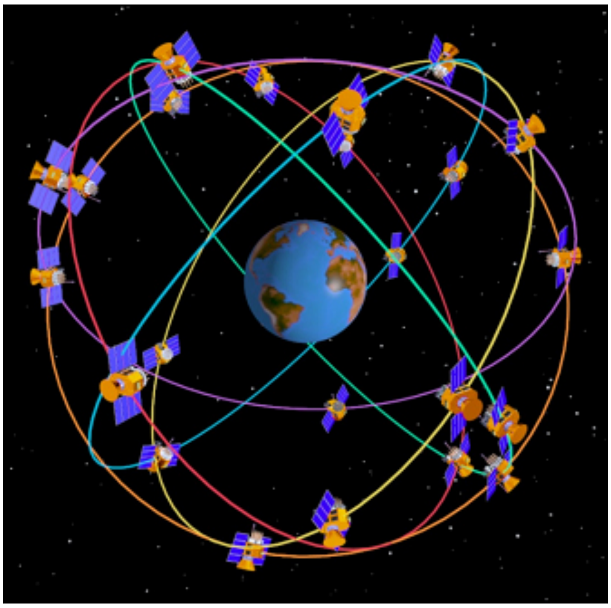
The basic constellation, or building bricks of GPS:

1. ***Space segment***: the satellites that orbit the Earth, and the radio signals that they emit.
2. ***Control segment***: the ground stations that monitor and maintain the space segment components.
3. ***User segment***: the users with their hard- and software to conduct positioning.

Ad 1) Space segment

The space segment of GPS consists of 24 satellites on 6 orbits (approx. 22,000 km from the centre of the Earth):

- Each satellite carries a clock
- Each satellite completes 2 orbits/day.
- 24 hour complete GPS coverage anywhere on the Earth.
- Accuracy: 21 meters 95% of time

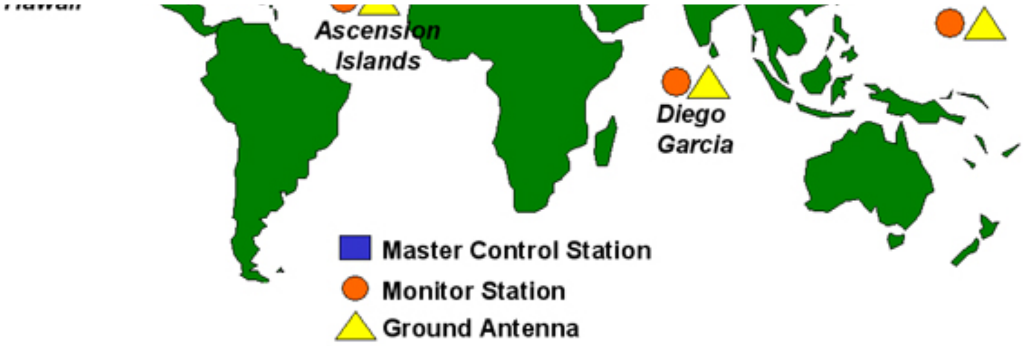


Ad 2) Control segment

The control segment is composed of

- a master control station (MCS),
- an alternate master control station,
- four dedicated ground antennas and
- six dedicated monitor stations

Home
|
Self study
:
Reference sytems
|
Contents
|
Intro
|
1.Graticule / topographic grid
|
2.Projection Systems (a/b/c/d)
|
3.Plane rectangular coordinate systems (a/b)
|
4.Coordinate transfor-mations
|
5.Satellite-based positioning (a/b)



Ad 3) User segment

The user segment is composed of hundreds of thousands of U.S. and allied military users of the secure GPS Precise Positioning Service, and tens of millions of civil, commercial and scientific users of the Standard Positioning Service.

In general, GPS receivers are composed of an ***antenna***, tuned to the frequencies transmitted by the satellites, ***receiver-processors***, and a highly stable ***clock*** (often a crystal oscillator).

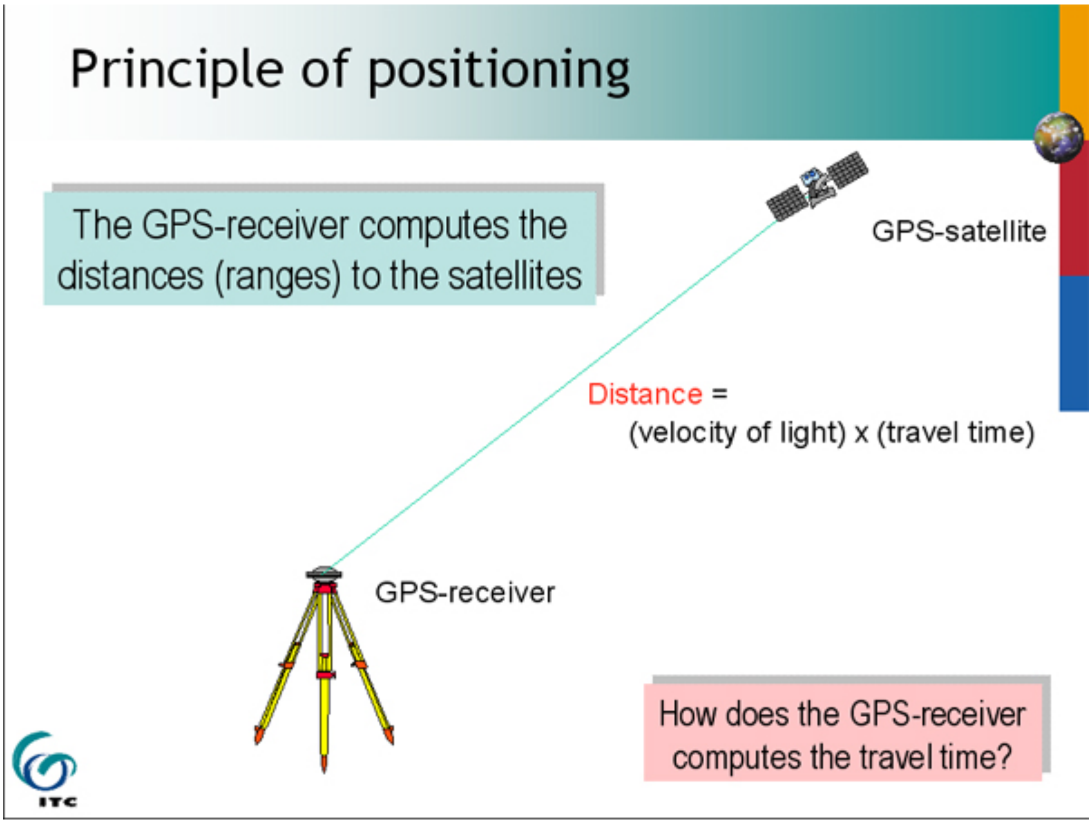
How to select a GPS receiver?

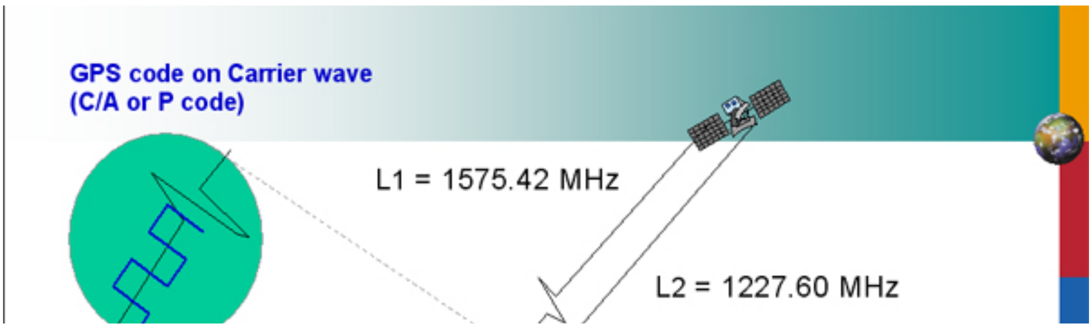
- Application (boating, flying, driving, mapping, surveying)
- Accuracy requirements
- Power consumption requirements
- Operational environment
- Signal processing requirements
- Cost
- Data exchange standard

1) Basic concept of GPS - Absolute Positioning

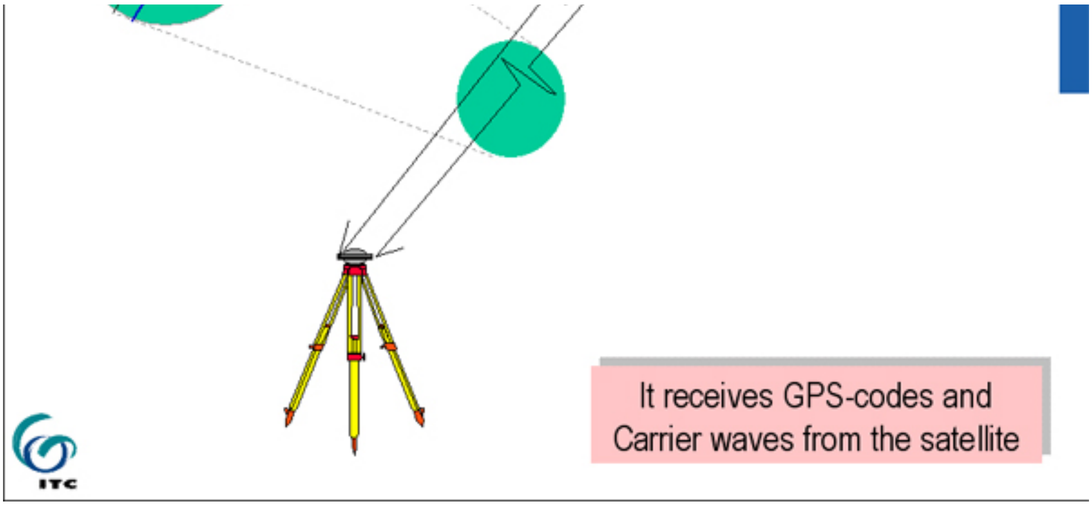
A GPS receiver calculates its position by precisely timing the signals sent by GPS satellites high above the Earth. Each satellite continually transmits messages that include

- the time the message was transmitted
- precise orbital information (the ephemeris)
- the general system health and rough orbits of all GPS satellites (the almanac).



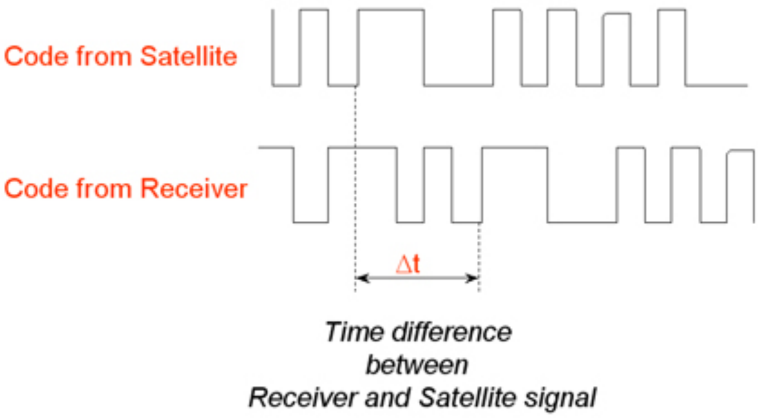


Home
|
Self study
:
Reference sytems
|
Contents
|
Intro
|
1.Graticule / topographic grid
|
2.Projection Systems (a/b/c/d)
|
3.Plane rectangular coordinate systems (a/b)
|
4.Coordinate transfor-mations
|
5.Satellite-based positioning (a/b)



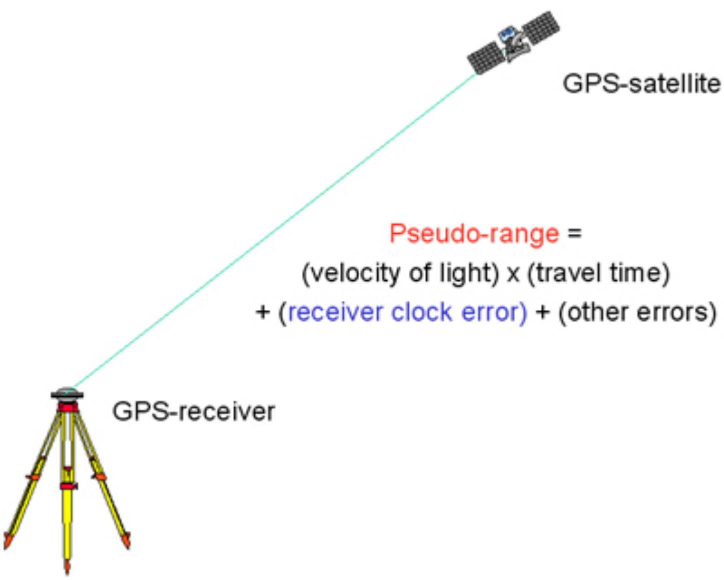
Source: Powerpoint presentation - Knippers, 2010

Then the codes are compared.



Source: Powerpoint presentation - Knippers, 2010

The GPS-receiver measures in fact pseudo distances (pseudo-ranges) to the satellites.



Source: Powerpoint presentation - Knippers, 2010

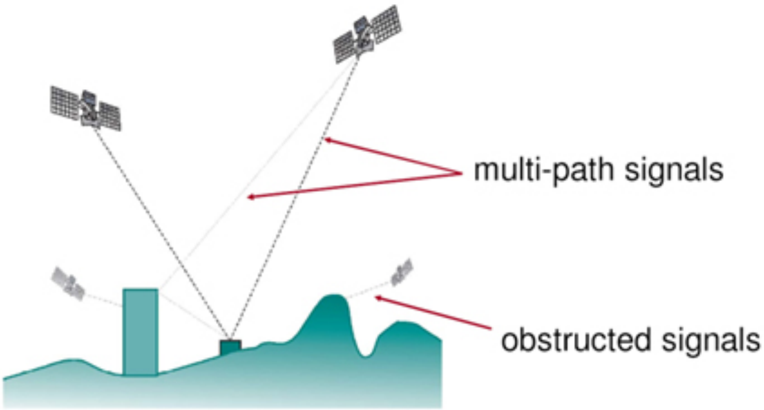
To determine a position in a three dimensional space it takes in theory three distance measurements from three satellites. But for accurate positioning an extra distance measurement from a fourth satellite toeliminate the receiver clock error, is required.

Error sources in the above absolute positioning due to:

- Selective availability
- Satellite clock and orbit errors

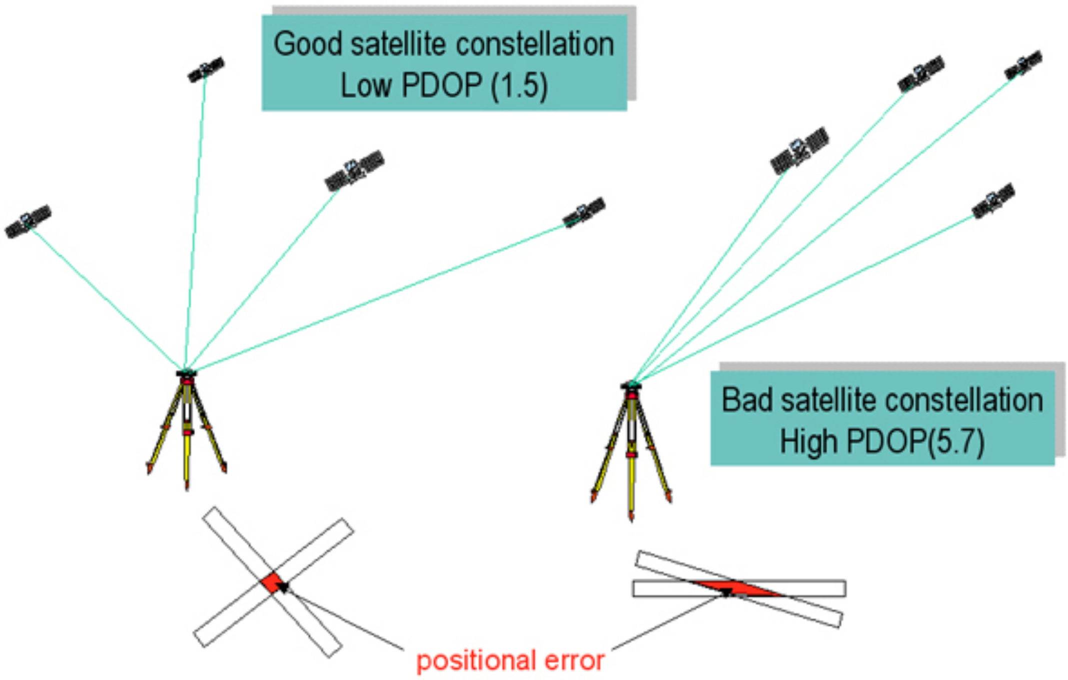
  One of the most significant error sources is the GPS receiver's clock. Because of the very large value of the speed of light, c, the estimated distances from the GPS receiver to the satellites (= the pseudoranges), are very sensitive to errors in the GPS receiver clock; for example an error of one microsecond (0.000 001 second) corresponds to an error of 300 metres (980 ft). This suggests that an extremely accurate and expensive clock is required for the GPS receiver to work.

- Ionospheric and tropospheric delays
- Receiver's environment (multi-path)



Source: Powerpoint presentation - Knippers, 2010

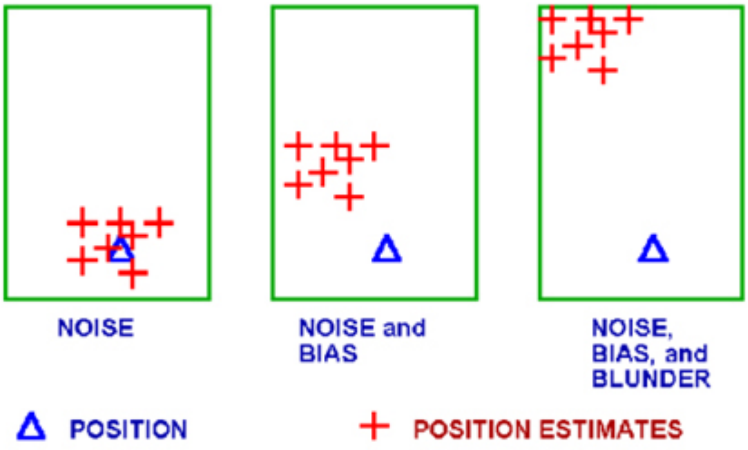
- Satellite constellation



Source: Powerpoint presentation - Knippers, 2010

- Location errors (noise, bias and blunder)
  - Noise (random) errors: noise in code and noise in receiver, multi-path.
  - Bias (systematic) errors: clock, satellite position, ionosphere, troposphere, GDOP effects

- Bias (systematic) errors: clock, satellite position, ionosphere, troposphere, GDOP effects.
- Blunder: incorrect geodetic datum, software failures, hardware problems etc.



Source: Powerpoint presentation - Knippers, 2010

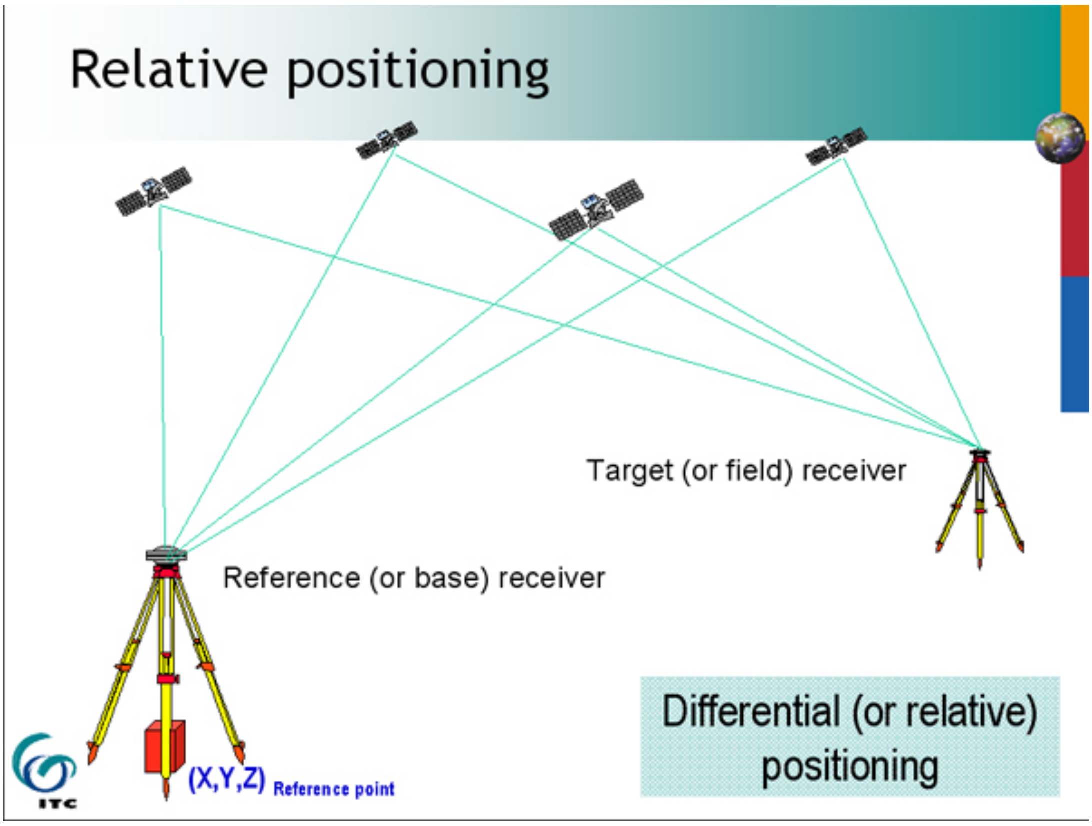
Positional *accuracy* in *absolute* positioning (based on code measurements):

Typical error: **5-10 m** (horizontal accuracy)

Typical error: **2-5 m** (horizontal accuracy) when using a dual-frequency receiver or the encrypted military signals (P-code)

2) Relative (or differential) positioning

Differential Global Positioning System (DGPS) is an enhancement to the absolute "Global Positioning System" that uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions. These stations broadcast the difference between the measured satellite pseudoranges and actual (internally computed) pseudoranges, and receiver stations may correct their pseudoranges by the same amount.



Source: Powerpoint presentation - Knippers, 2010

Positional *accuracy* in *relative* positioning

Typical error: **0.5 - 5m** (horizontal accuracy), based on code measurements

Typical error: **2mm – 2cm** (horizontal accuracy), based on carrier phase measurements.

Carrier phase measurement is a technique to measure the range (distance) of a satellite by determine the number of cycles of the (sine-shaped) radio signal between sender and receiver. The number of cycles is determined in a long observation session.

<previous

AVAILABLE EXERCISES

next>

Exercise 1: Calculate your Geoid height

Online exercises:

Exercise: Measure Latitude and Longitude - the challenge

Home
|
Exercises
:
Reference systems
|
1.Calculate your Geoid height
|
2.Online exercise

next>

EXERCISE 1: CALCULATE YOUR GEOID HEIGHT

<previous-next>

Home
|
Exercises
:
Reference systems
|
1.Calculate your Geoid height
|
2.Online exercise

Determine the geographic coordinates of the location your are at, and calculate your geoid height.

Tip: Read Chapter 3. "Reference surfaces for mapping" of the website on "Geometric aspects on mapping", very carefully.

<previous-next>

EXERCISE 2: ONLINE EXERCISE

<previous

Click on the below link for online exercise.

Exercise: Measure Latitude and Longitude - the challenge

Home
|
Exercises
:
Reference systems
|
1.Calculate your Geoid height
|
2.Online exercise

<previous

DOCUMENTS AND LITERATURE

Available documents:

- D06-01: Kadmon, N. and R. Knippers (2002). *The definitions of location*.
- D06-02: Knippers, N. (2002). *Maps, Geodetic and cartographic reference systems.* Powerpoint presentation given the DGSD-UNGEGN Toponymy Course in Enschede /Frankfurt am Main, The Netherlands/Germany (pdf).
- D06-03: Knippers, N. (2010). *Spatial referencing.* Teaching material, Faculty of Geo-Information Science and Earth Observation, University of Twente, the Netherlands.
- D06-04: Knippers, N. (2010). *Satellite-based positioning.* Teaching material, Faculty of Geo-Information Science and Earth Observation, University of Twente, the Netherlands.

Literature:

- Kadmon, N. (1996). *The definitions of location*. In P.S.Hattingh, N.Kadmon, P.E. Raper and I. Booysen (eds) - UNGEGN Training Course in Toponymy for Southern Africa Department of Geography, University of Pretoria, Pretoria 1993. ISBN 0-86979-909-6. (to be ordered from Dept of Geography, University of Pretoria, Pretoria 0002, South Africa. Fax (012) 420 3284), pp 29-37 (pdf).

- Knippers, R.A and J. Hendrikse (2001). *Coordinate transformations*. Kartografisch Tijdschrift, KernKatern 2000-3 (URL / pdf).

- Kraak, M.J. and F.J. Ormeling (2010). *Cartography, Visualization of spatial data*. New York, London, Guilford Press, 2011. ISBN: 978-1-60918-193-2.

Online resources:

- Geometric aspects of mapping / by Richard Knippers (ITC)

- Concepts of geographical referencing systems / by Graduate School of Design, Harvard University)

- Explore the challenges: Measure Latitude and Longitude / by Rough Sciences, PBS.

  The United Nations sell the following publications which also can be downloaded from the UNGEGN website:

  - Glossary of Terms for the Standardization of Geographical Names (New York 2002) / pdf
  - Manual for the national standardization of geographical names (UN - Ecosoc, New York, 2006 ST/ESA/STAT/SERM/88 Sales No. E.06.XVII.7 ISBN 92-1-161490-2, available in the 6 UN languages) / pdf
  - Technical reference manual for the standardization of geographical names (New York, 2007) / pdf
  - Resolutions adopted at the nine UN Conferences on the standardization of geographical names (English (pdf) / French (pdf)