Spatial referencing

An overview

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Learning instructions

Learning activities:

- Literature: ITC Core textbook, Chapter 3.1 on Spatial Referencing.
- Website: http://kartoweb.itc.nl/geometrics
- Exercise: Spatial referencing (ArcMap10)

Questions: Blackboard Discussion Board

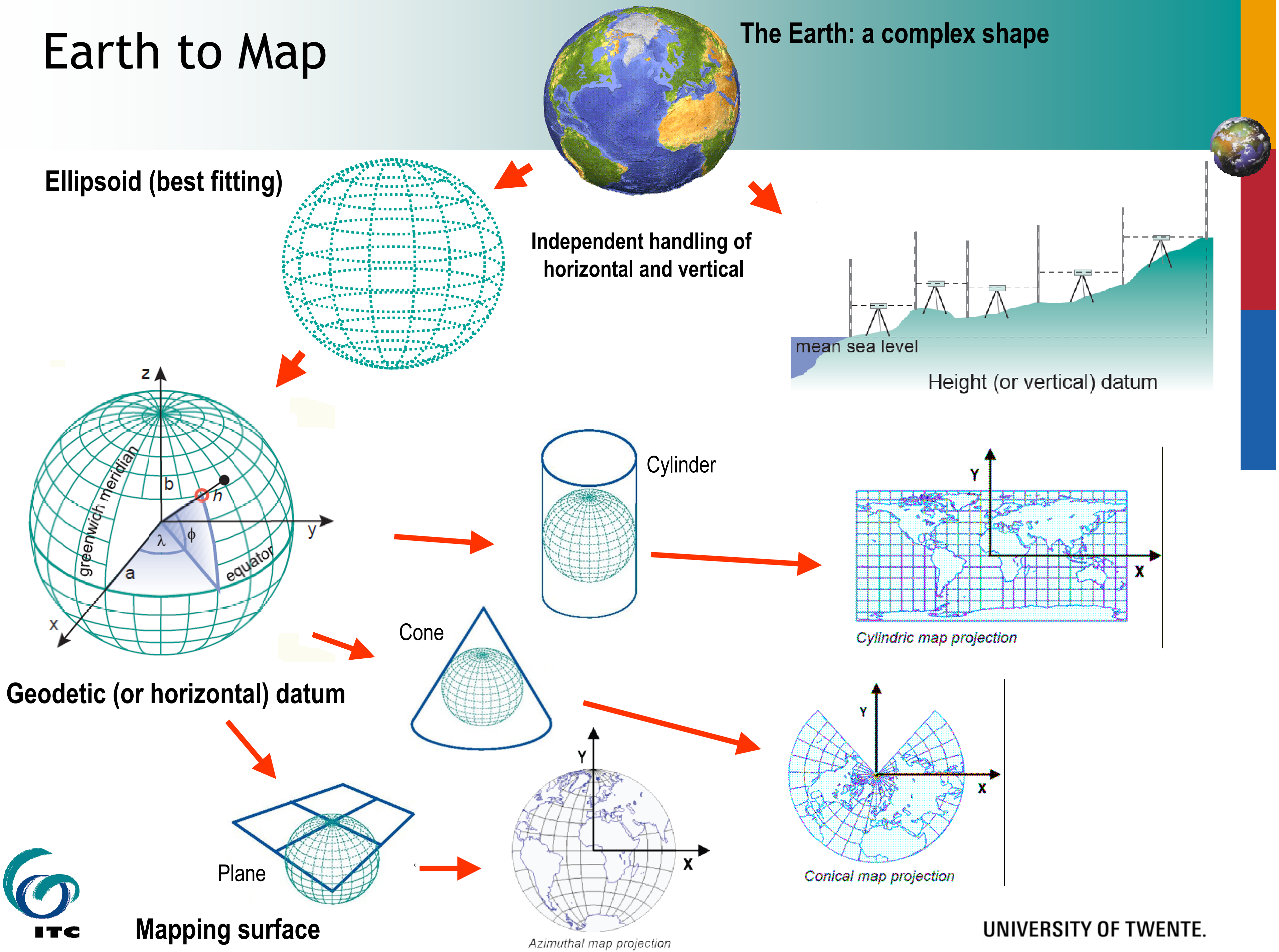
Main objectives

- Understand the relevance and actual use of reference surfaces, coordinate systems, and coordinate transformations in mapping.
- Describe and differentiate between coordinate systems and map projections.
- Grasp the logic of map projection equations and the principles of transforming maps from one projection system to another.

Contents

- Spatial reference surfaces and datums
  - The Geoid – vertical (height) datum
  - The Ellipsoid – horizontal (geodetic) datum
  - Local and global datums
- Map projections
  - Classification of map projections
  - Map projection selection
  - Map coordinate systems (e.g. UTM)
- Coordinate transformations

Earth to Map



The Earth: a complex shape
Ellipsoid (best fitting)
Independent handling of horizontal and vertical
mean sea level
Height (or vertical) datum
z
y
x
b
h
a
λ
ϕ
greenwich meridian
equator
Geodetic (or horizontal) datum
Cylinder
Cone
Plane
Mapping surface
Y
X
Cylindric map projection
Conical map projection
Azimuthal map projection
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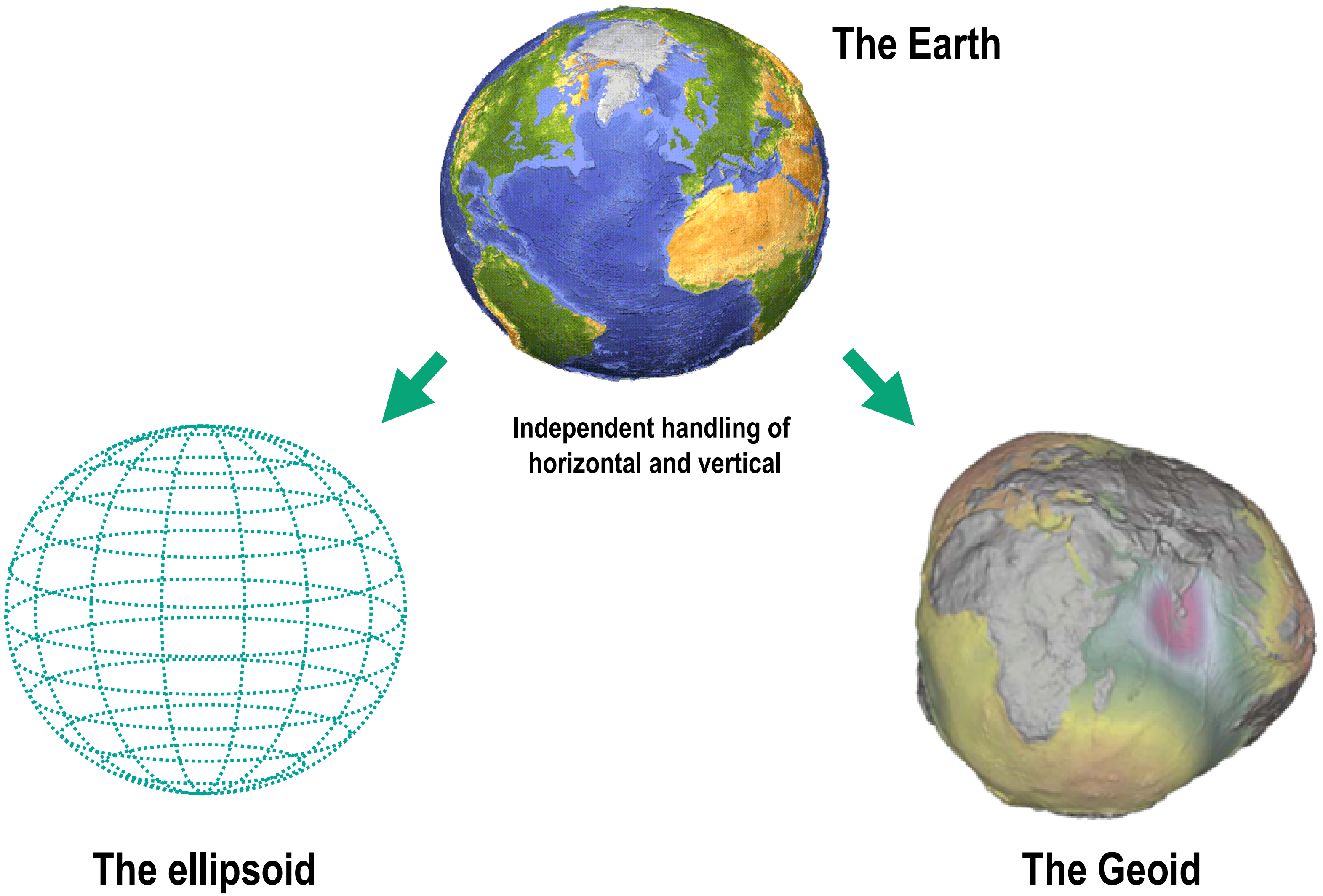
Reference surfaces for mapping



Spatial reference surface
-
The Geoid

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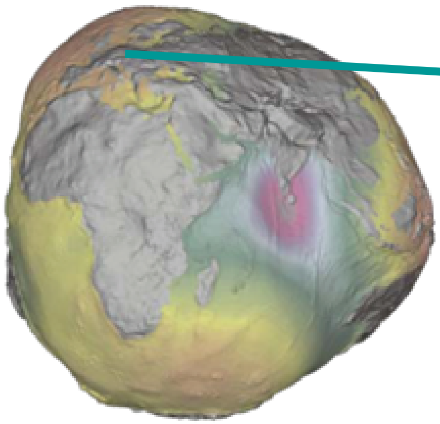
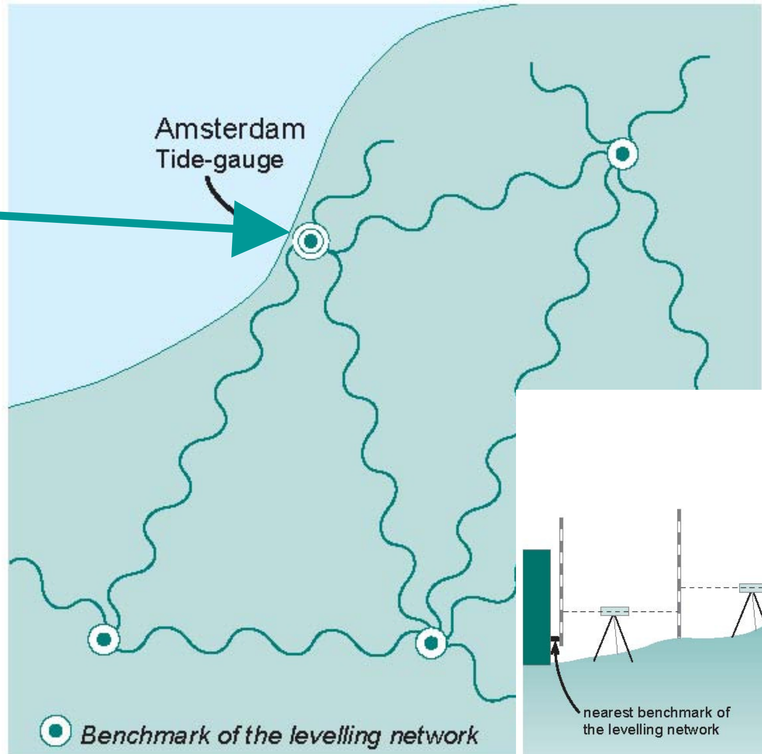
The Geoid – Vertical (height) datum

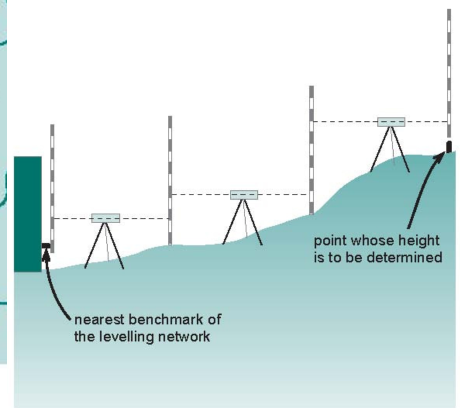
The Earth

The Geoid



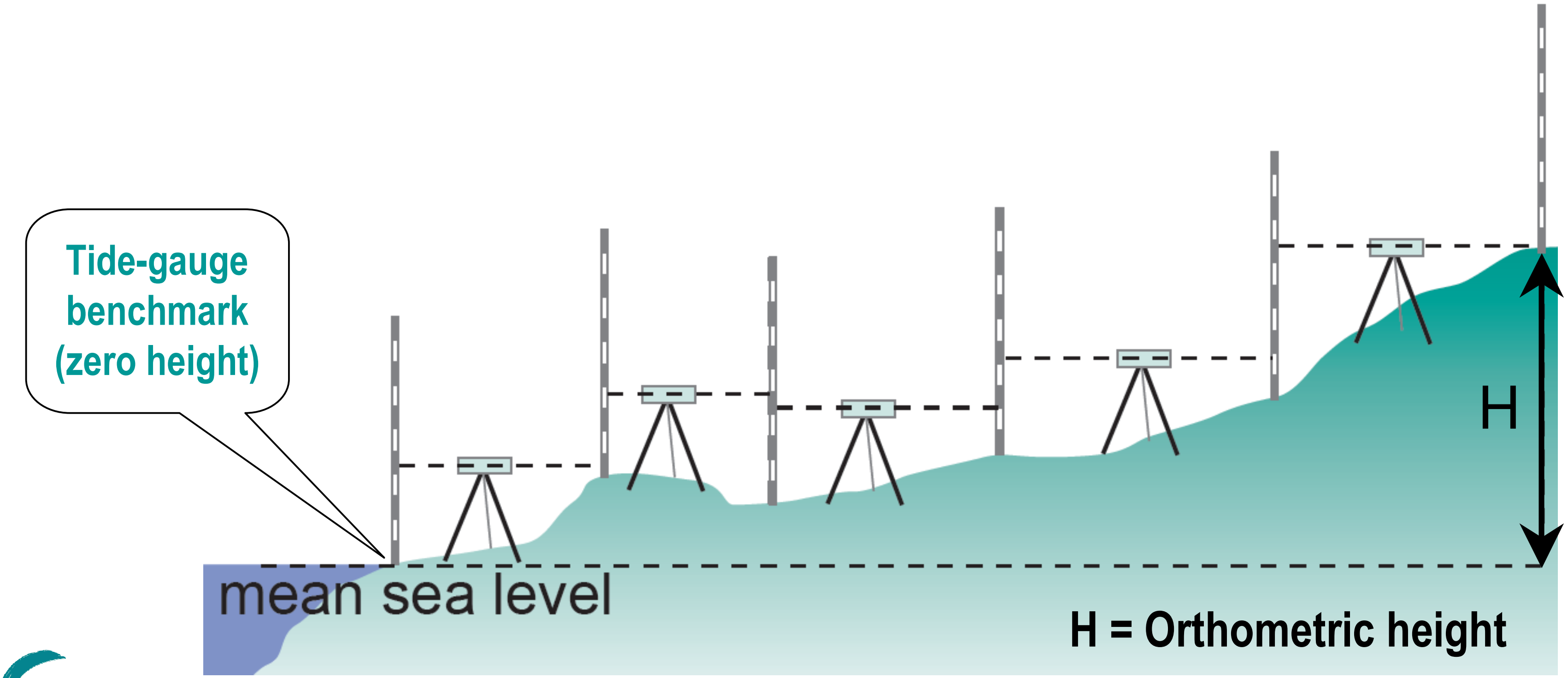
Global Sea Level





Geodetic levelling

Starting from Mean Sea Level (MSL) points, the heights (H) of points on the Earth can be measured using a technique known as geodetic leveling.



Vertical datums

Every country (or group of countries) has it's own Mean Sea Level - its own vertical (height) datum.

MSL of Belgium is 2.34m lower than MSL of The Netherlands

At what height do we live?

http://www.ahn.nl/postcodetool

Elevation data are related to Amsterdam Zero (N.A.P.)

GPS height versus N.A.P. height

GPS Reference Stations

GPS Reference Stations

Enschede

Station ID
0550

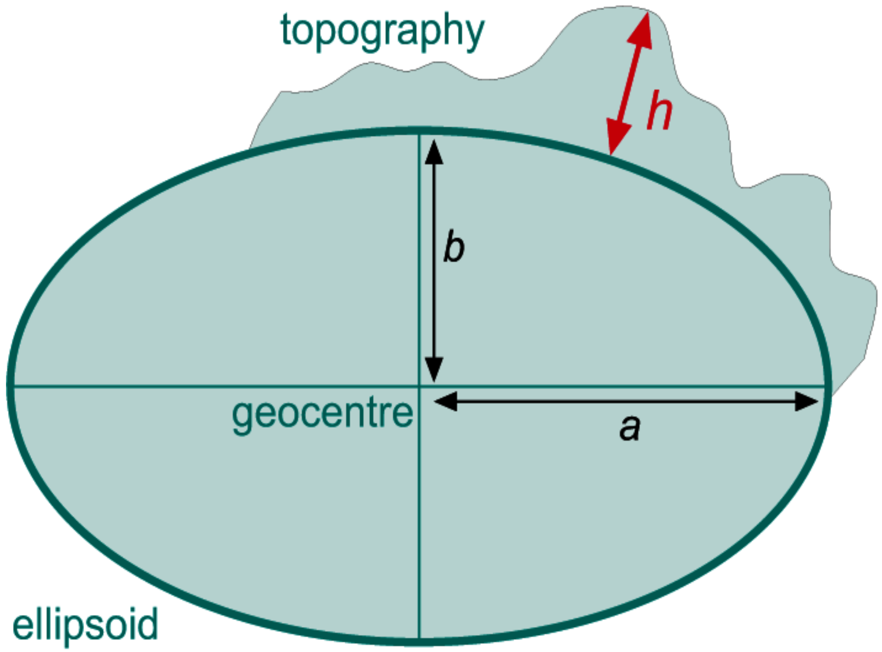
Position and Height
52 13'25" N
6 53'10" E
107,51 m → h_{WGS84} = 107.5m

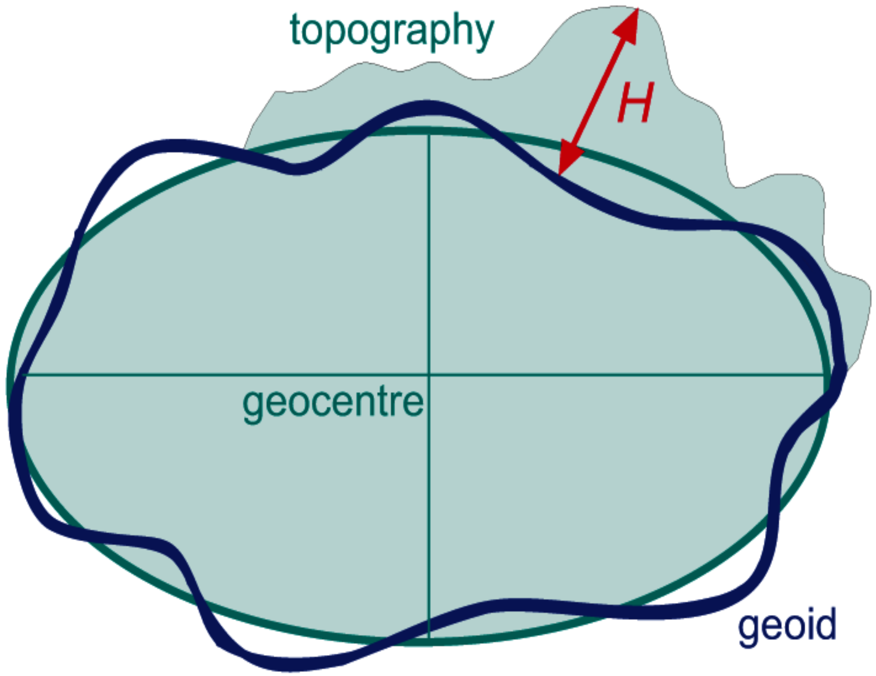
Location
This station is located on the roof of the International Institute for Geo-Information Science and Earth Observation (ITC) in the centre of Enschede.

This station is sending RTCM 18/19 RTK data and storing static data 24 hours a day. This stations is also a part of the GlobalNET and receives the GLONASS signal.

$H_{NAP} = h_{WGS84}$ - 44m (N) - 27m (ITC building) = **37m**

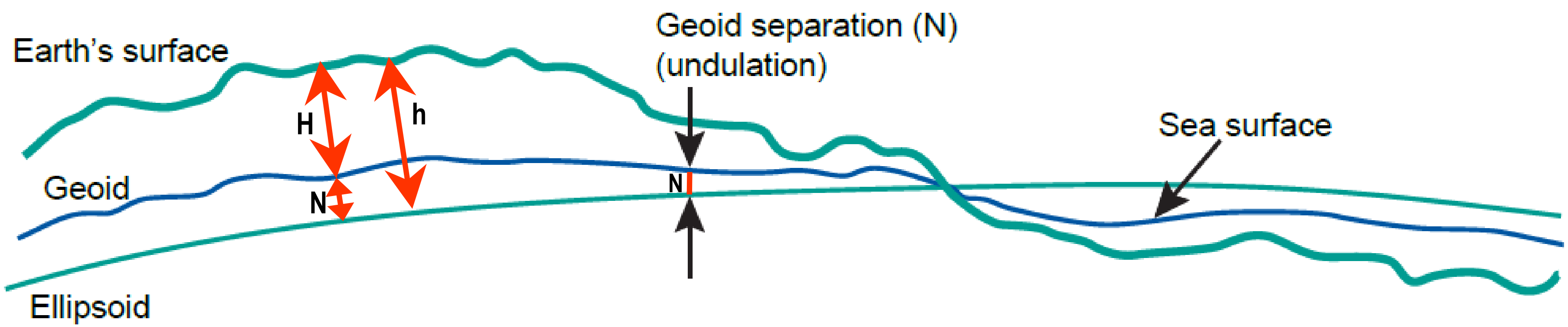
Ellipsoidal height versus Orthometric height





Relation between Geoid and Ellipsoid

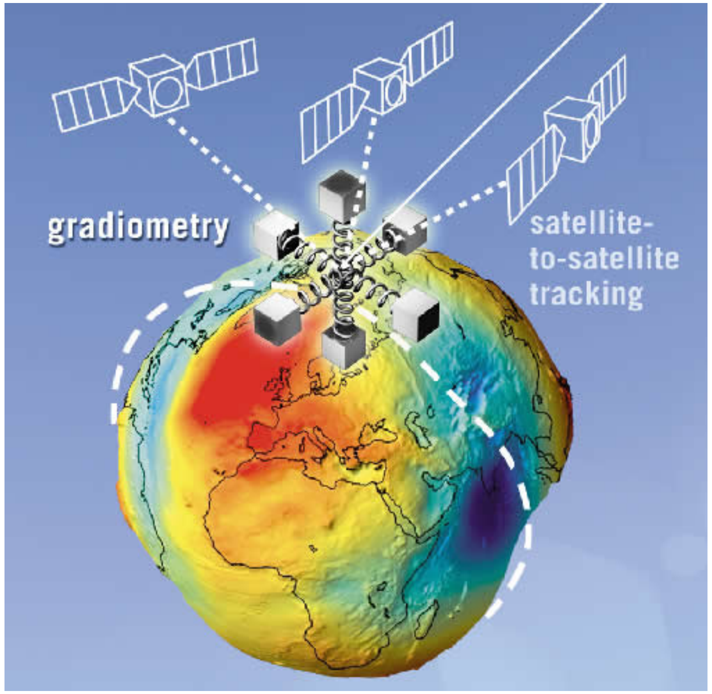
The earth's surface, and the geoid and a reference ellipsoid used to approximate it. The geoidal undulation (N) is the separation between the geoid and an ellipsoid. It varies globally between ±110 m.



H = Orthometric height
h = Ellipsoidal height
N = Geoidal separation (undulation)

Trends in mapping: global vertical datums

Satellite gravity missions (e.g. GOCE) make it possible to determine a global vertical datum with centimetres accuracy.



Spatial reference surface

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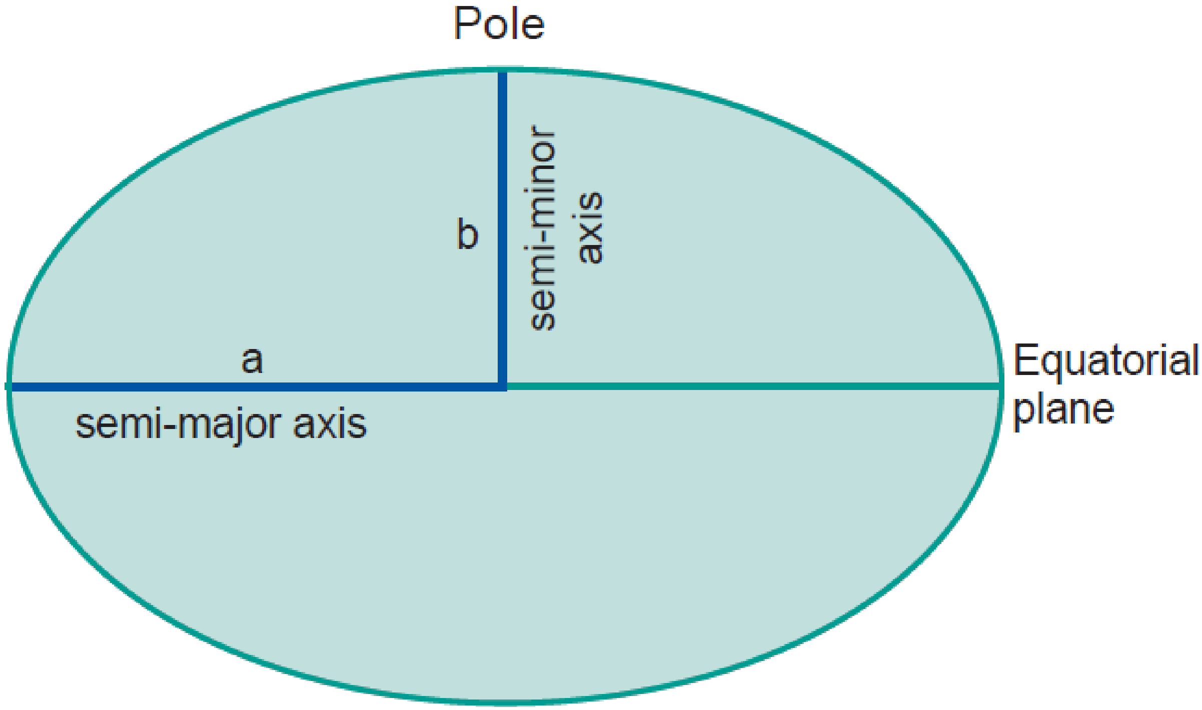
The Ellipsoid

The Ellipsoid



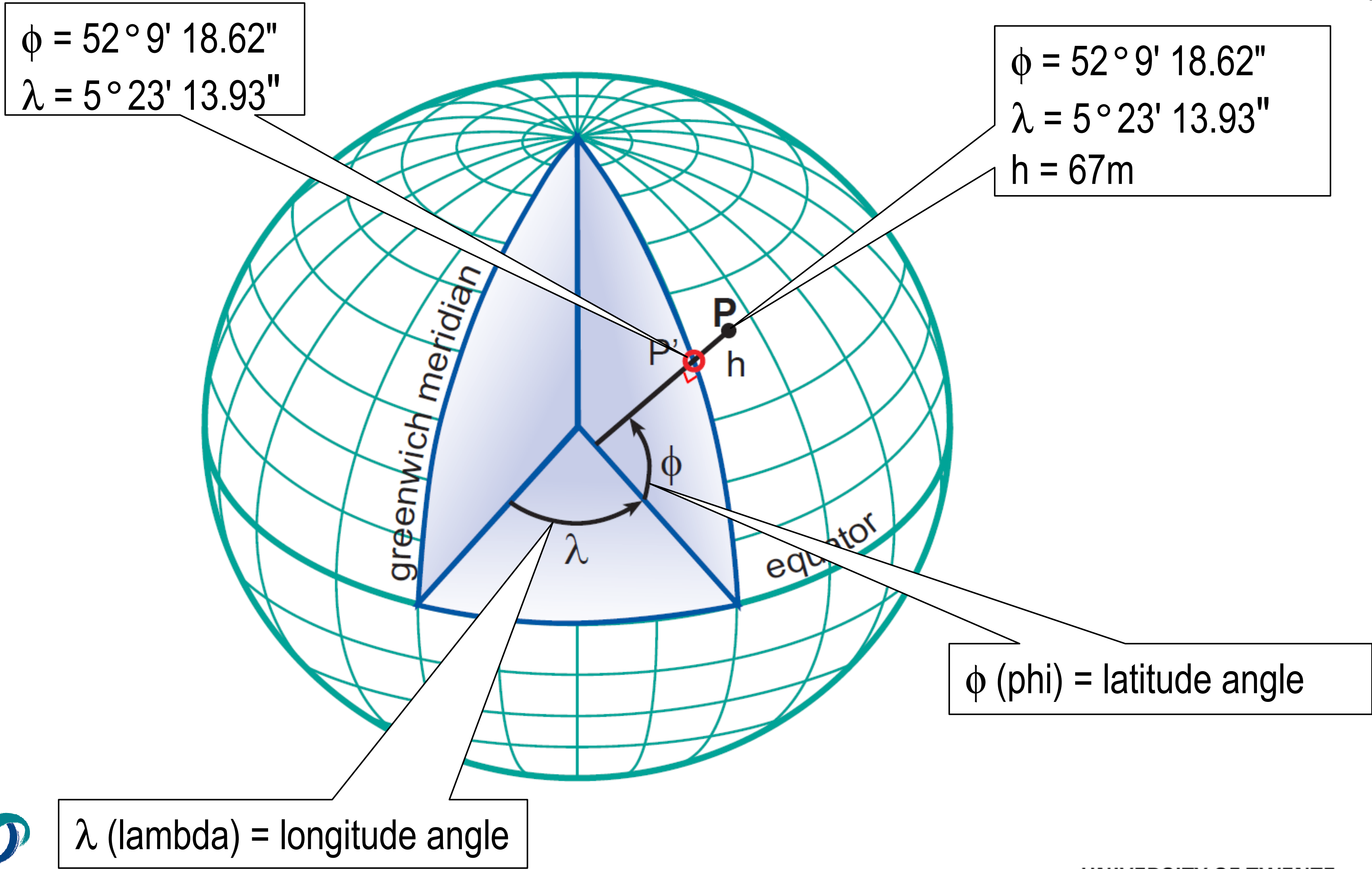
Typical values of the parameters for an ellipsoid:

a = 6378137.0 m   b = 6356752.31 m
f = 1/298.26   e = 0.0818187

Flattening:
$f = (a-b)/a$

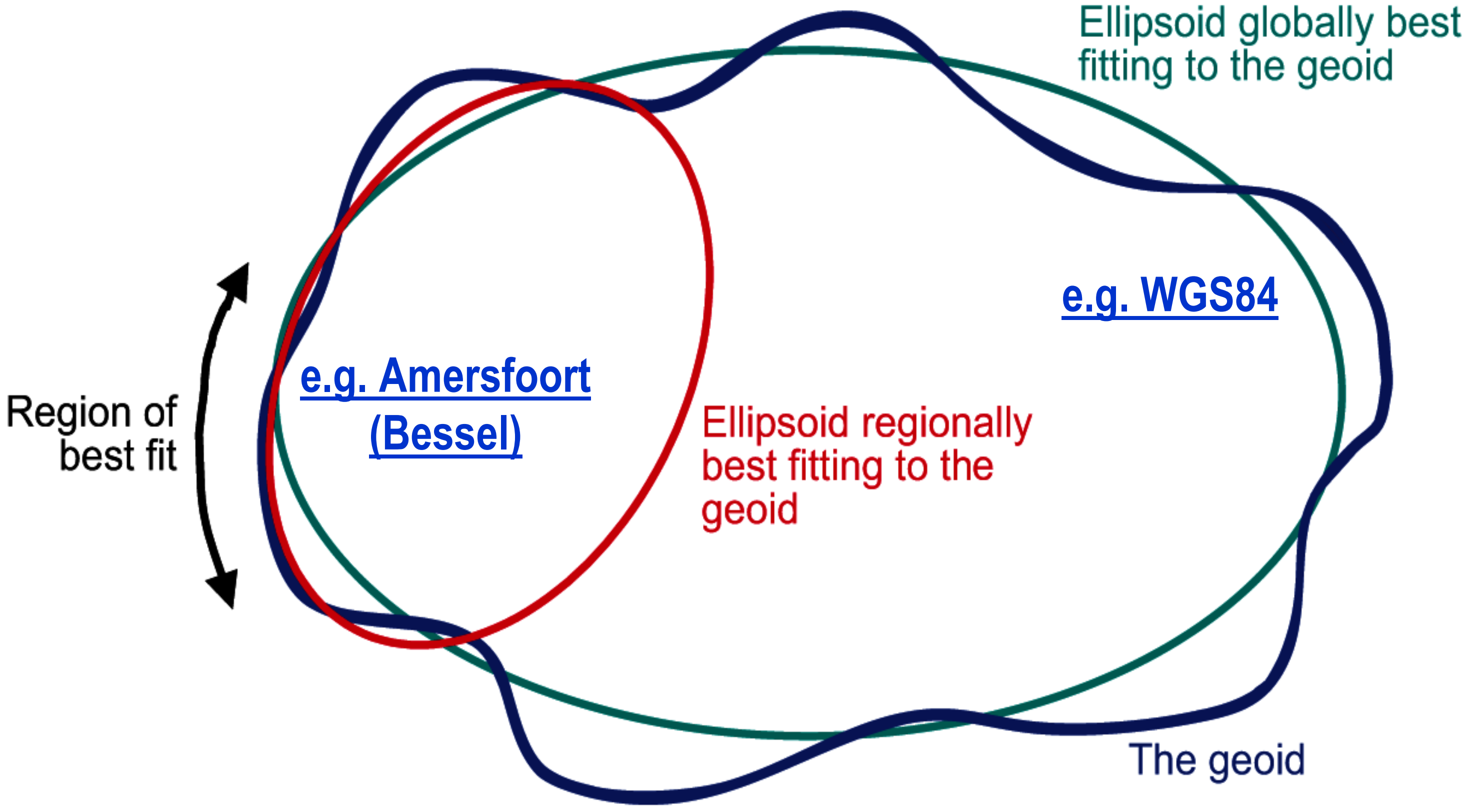
Eccentricity:
$e^2 = (a^2 - b^2)/a^2$

Geographic coordinates (φ, λ)

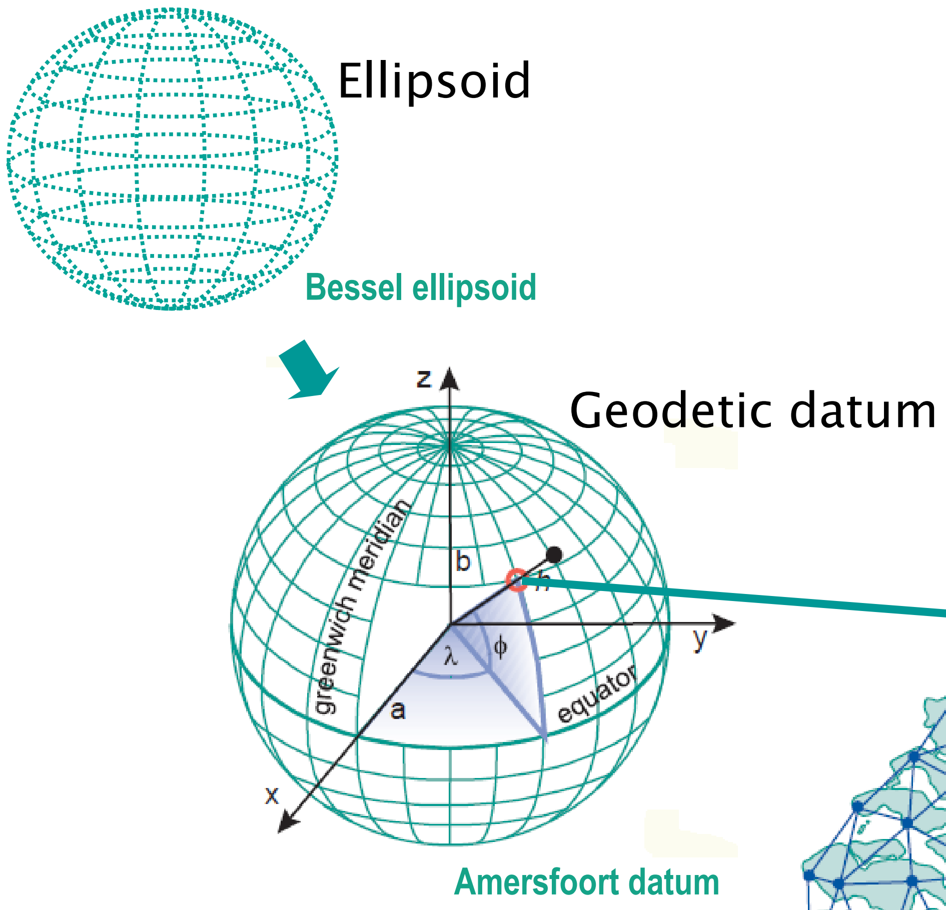


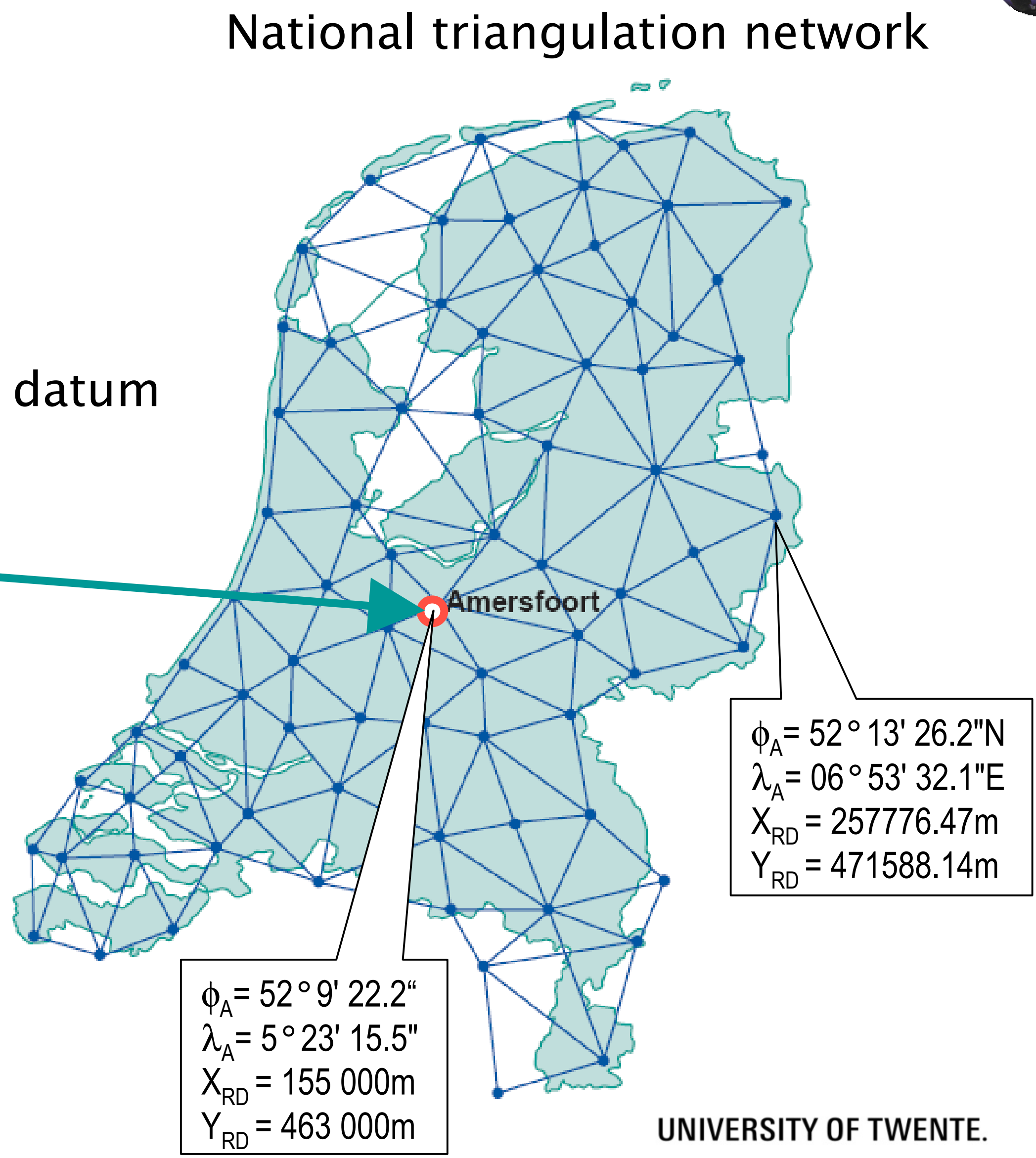
Local and global ellipsoids/datums

The ellipsoid is chosen in such way that it best fits the surface of the area of interest (the country)



Local datum system of the Netherlands





Local datum systems

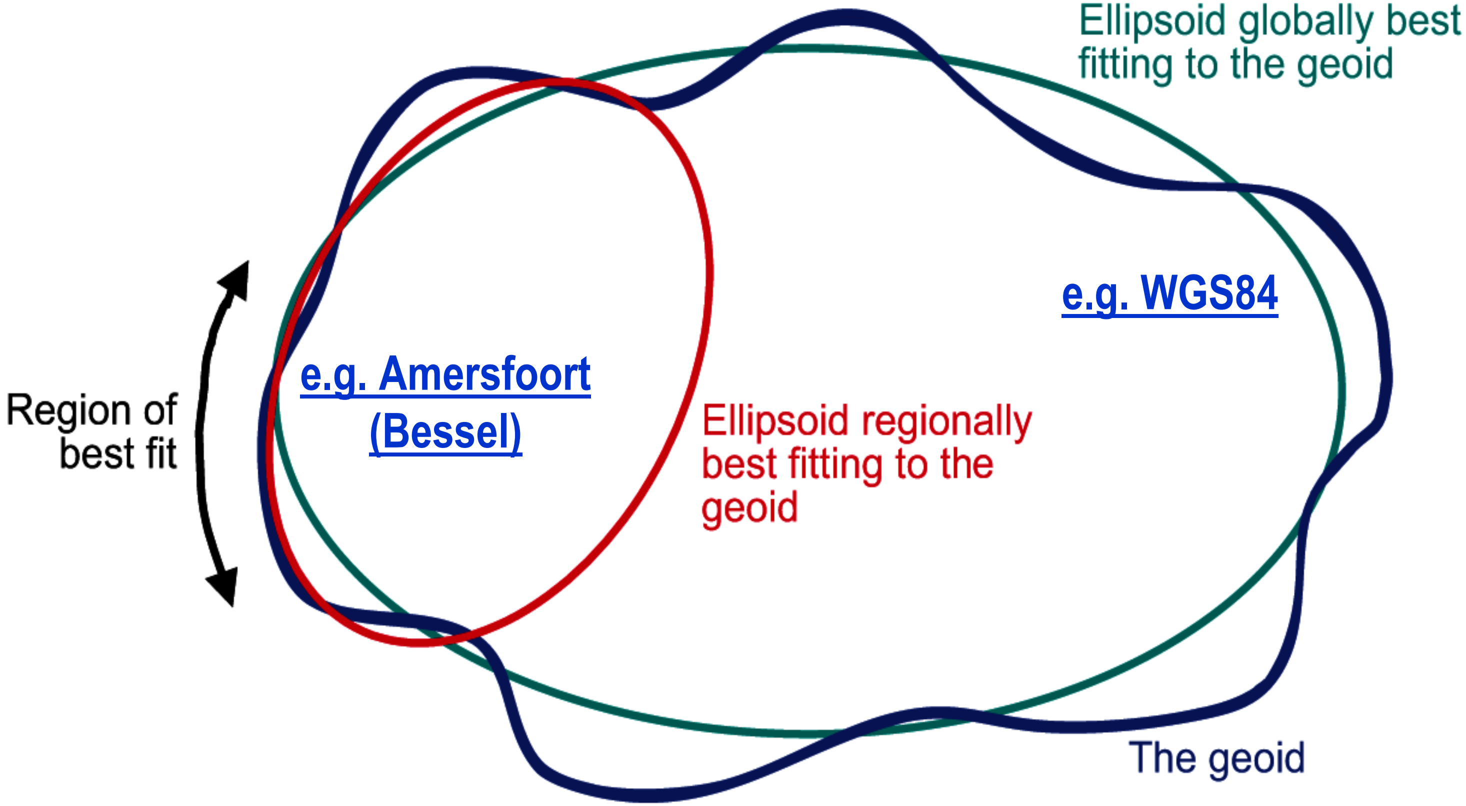
Datum	Ellipsoid	Datum shift (m)* (Dx,	Dy,	Dz)
Alaska (NAD-27)	Clarke 1866	-5	135	172
Bahamas (NAD-27)	Clarke 1866	-4	154	178
Bermuda 1957	Clarke 1866	-73	213	296
Central America (NAD-27)	Clarke 1866	0	125	194
Bellevue (IGN)	Hayford	-127	-769	472
CampoInchauspe	Hayford	-148	136	90
Hong Kong 1963	Hayford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

** positions compared to WGS84*

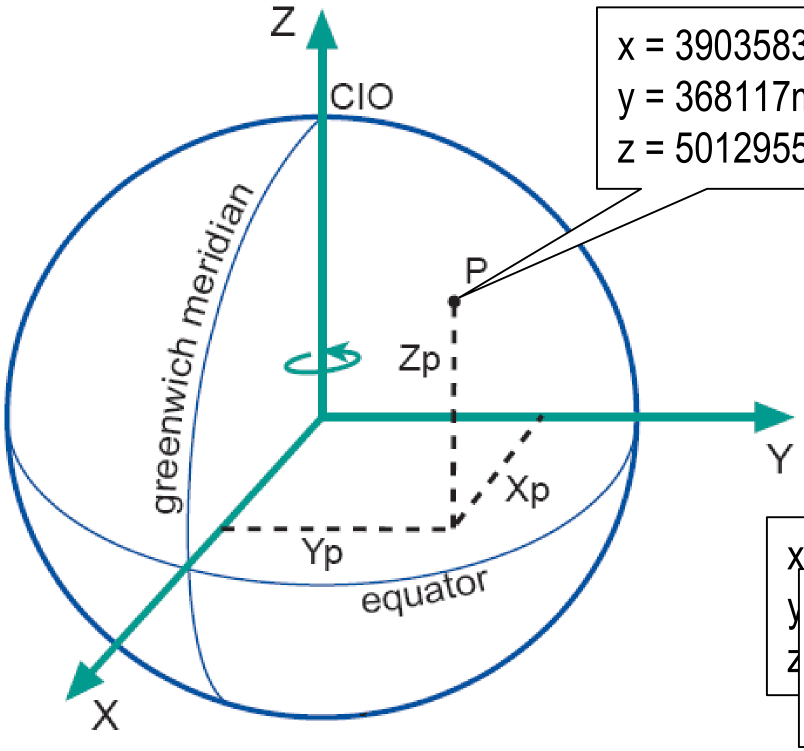
Countries (or regions) use there own datum system to make accurate maps.

Local and global ellipsoids/datums

The ellipsoid is chosen in such way that it best fits the surface of the area of interest (the country)



International Terrestrial Reference System (ITRS)



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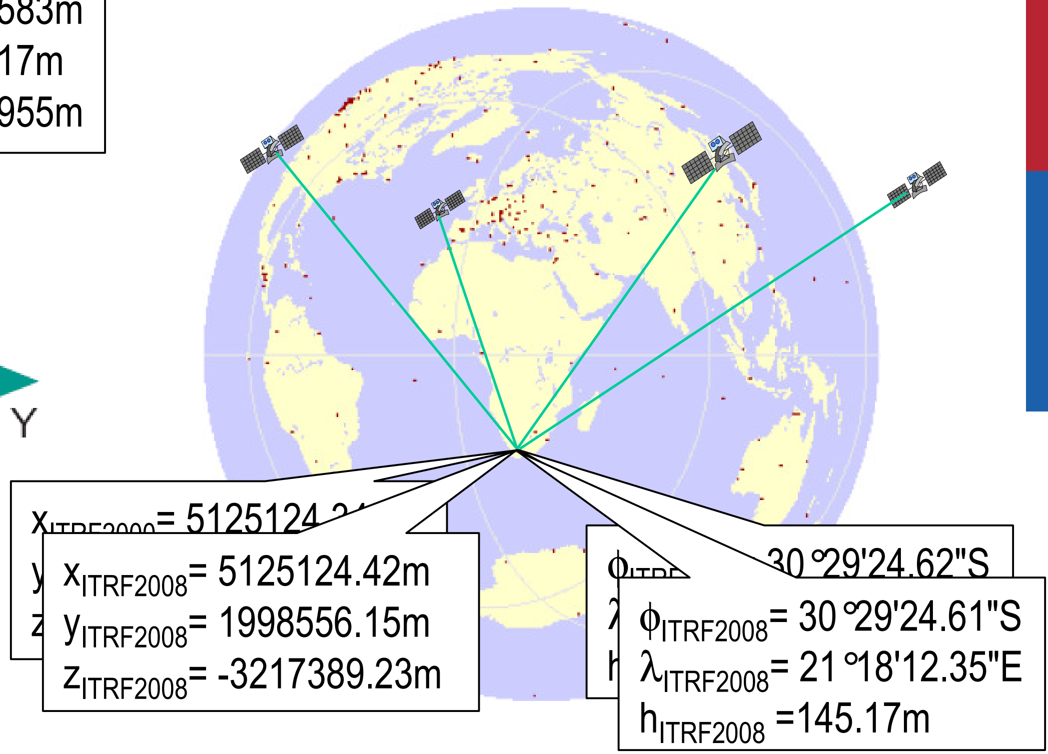

International Terrestrial Reference Frame (ITRF)

Global reference system for global surveying and mapping.
The system uses the GRS80 (or WGS84) ellipsoid

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Trends in mapping: global horizontal datums

Global ellipsoids and datums
to approximate the earth-as-a-whole - with the aid of satellites- are becoming more in use
(e.g. WGS84, ITRF, ETRS89).

Changing or re-adjustment of local ellipsoids and datums is taking place in many countries.

Map projections

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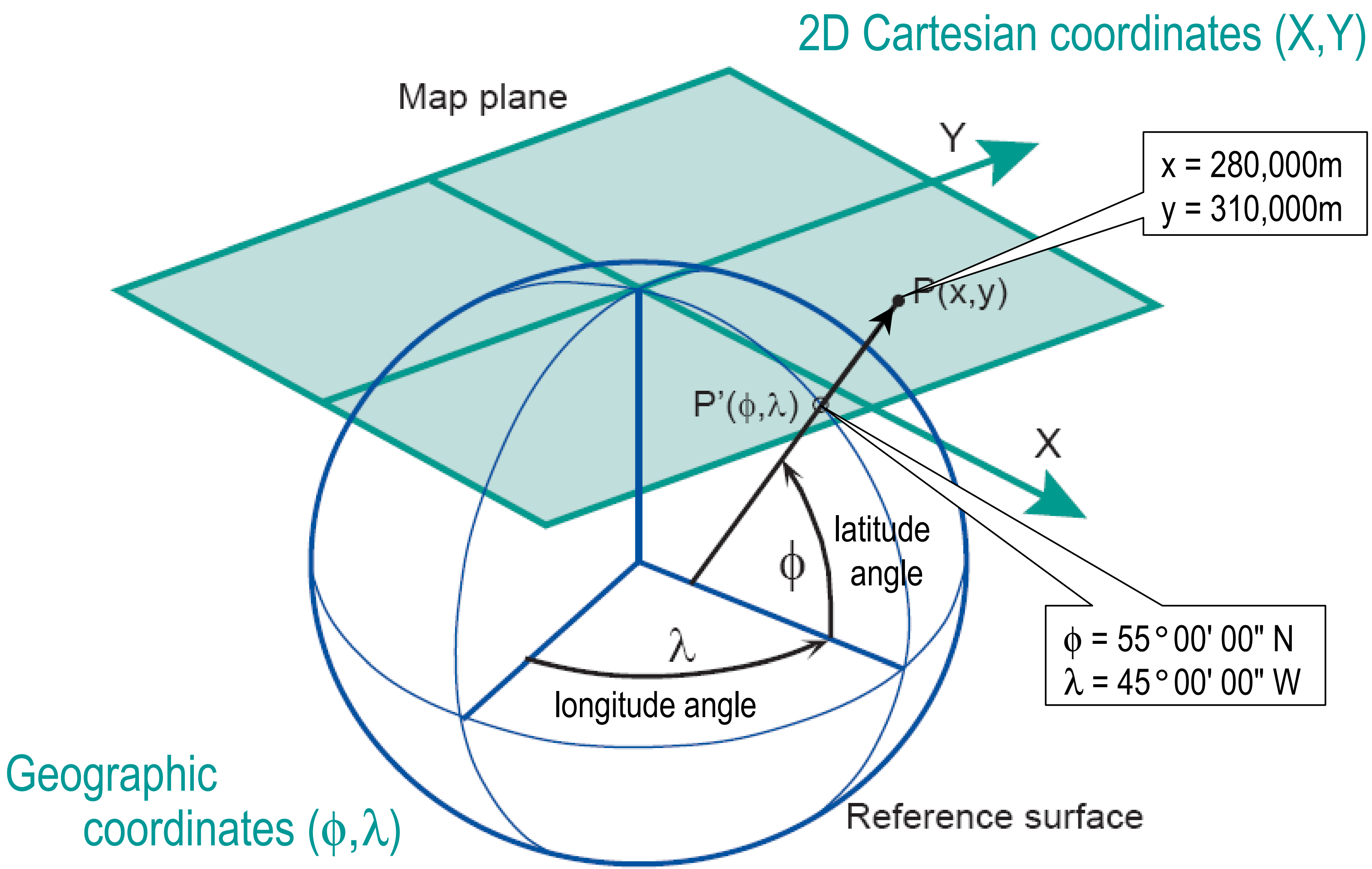
Map projection principle



Map projection equations

A map projection is a mathematical function by which 2D Geographic coordinates(ϕ,λ) are transformed into 2D Cartesian map coordinates (x,y)

$$(x, y) = f(\phi, \lambda).$$ *Forward equation*

$$(\phi, \lambda) = f^{-1}(x, y).$$ *Inverse equation*

Map projection equations (example)

Map projection equations for the Mercator projection (spherical assumption)

Forward mapping equation:

$$x = R(\lambda - \lambda_0)$$

$$y = R(ln(tan(\frac{\pi}{4} + \frac{\phi}{2})))$$

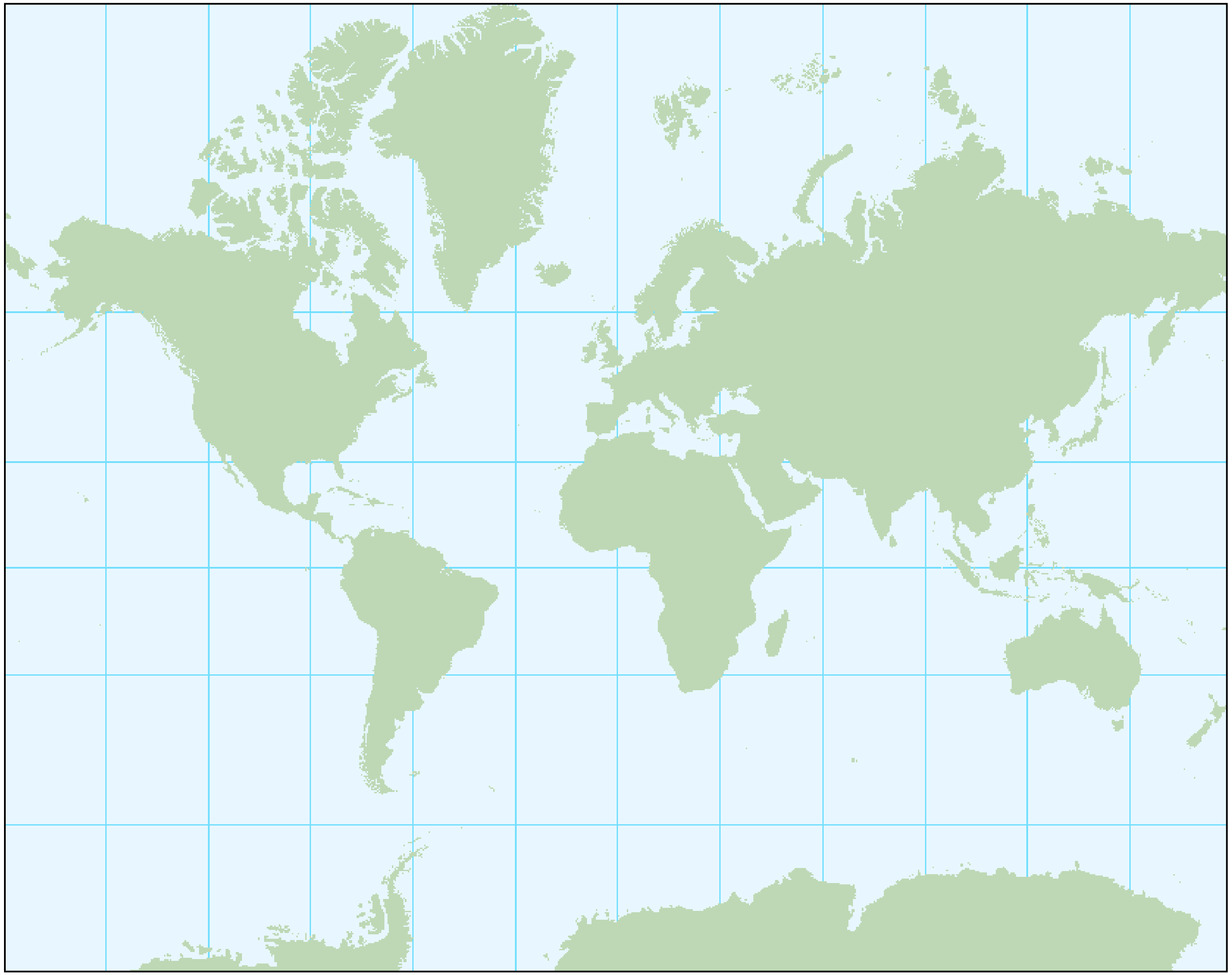
Inverse mapping equation:

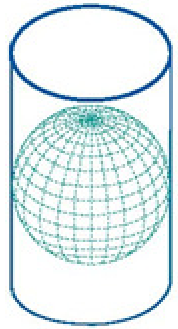
$$\phi = \frac{\pi}{2} - 2\arctan(e^{\frac{-y}{R}})$$

$$\lambda = \frac{x}{R} + \lambda_0$$

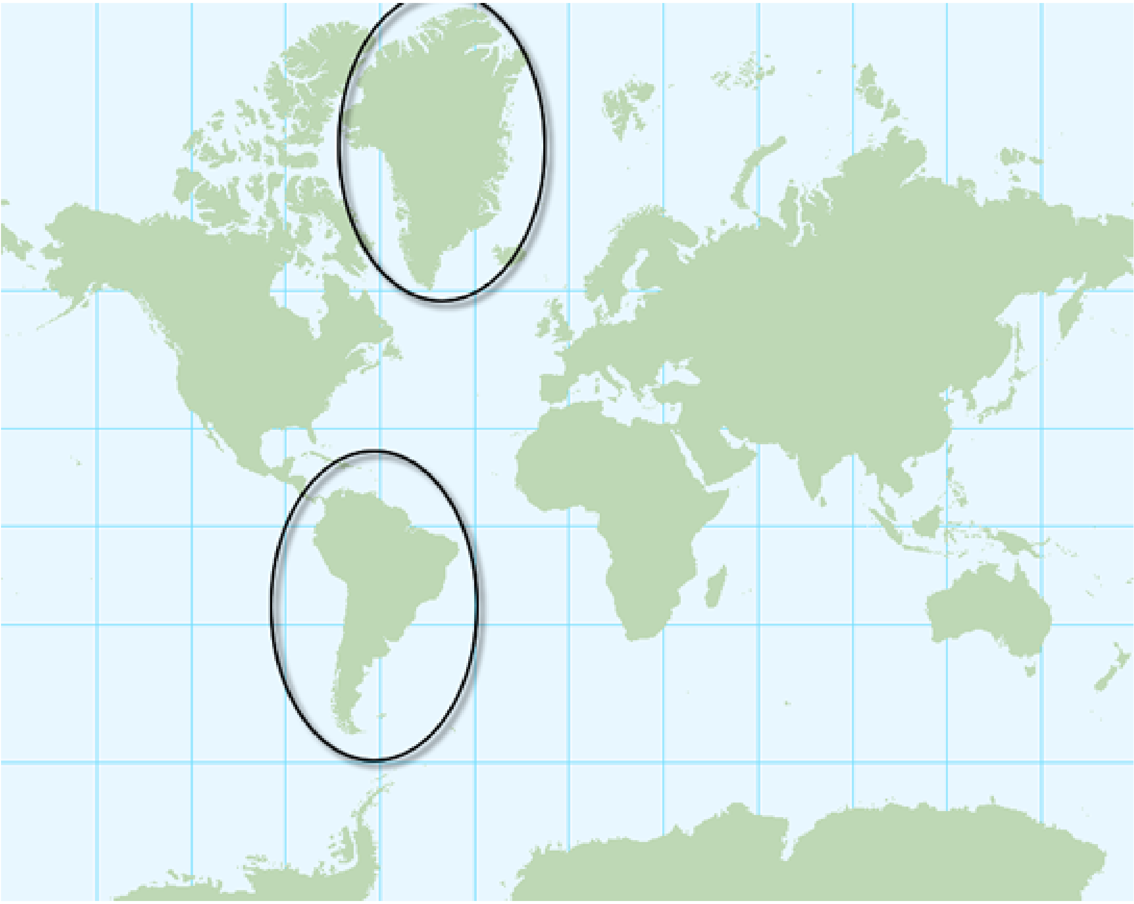
Mercator projection

Conformal cylindrical projection



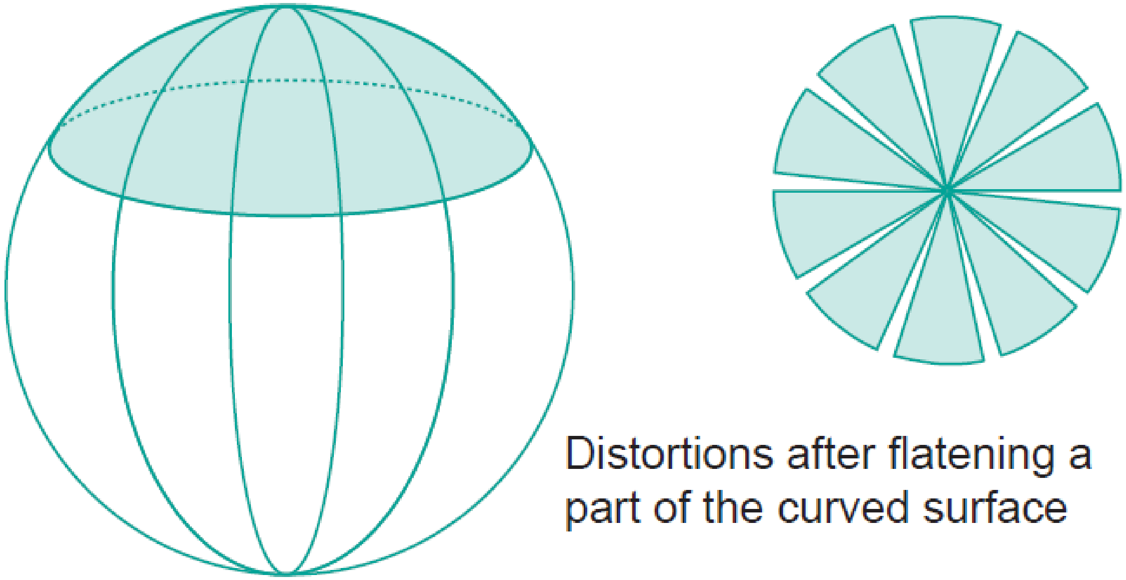


Scale distortions on the Mercator projection



Area distortions are significant towards the polar regions. Greenland appears to be larger but is only one-eighth the size of South America.

Scale distortions on a map



Distortions after flatening a part of the curved surface

Areas smaller than 25 x 25 km: NO DISTORTIONS

Areas larger than 25x25 km: ALWAYS DISTORTIONS

Any map projection is associated with scale distortions. The amount and kind of distortions depend on the type of map projection.

Map projection properties

Conformal

Angles and shapes are correctly represented (locally)

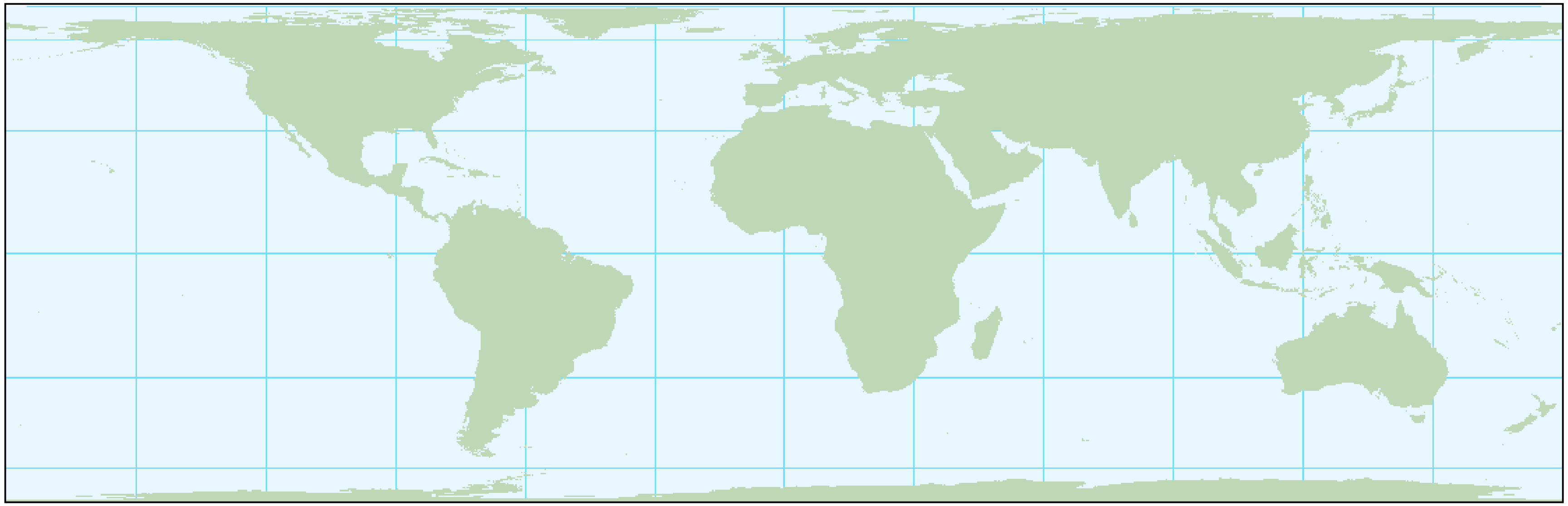
Equivalent (or equal-area)

Areas are correctly represented

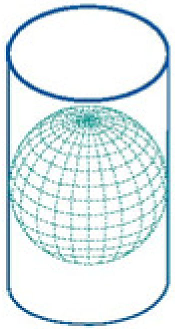
Equidistant

Distances from 1 or 2 points or along certain lines are correctly represented

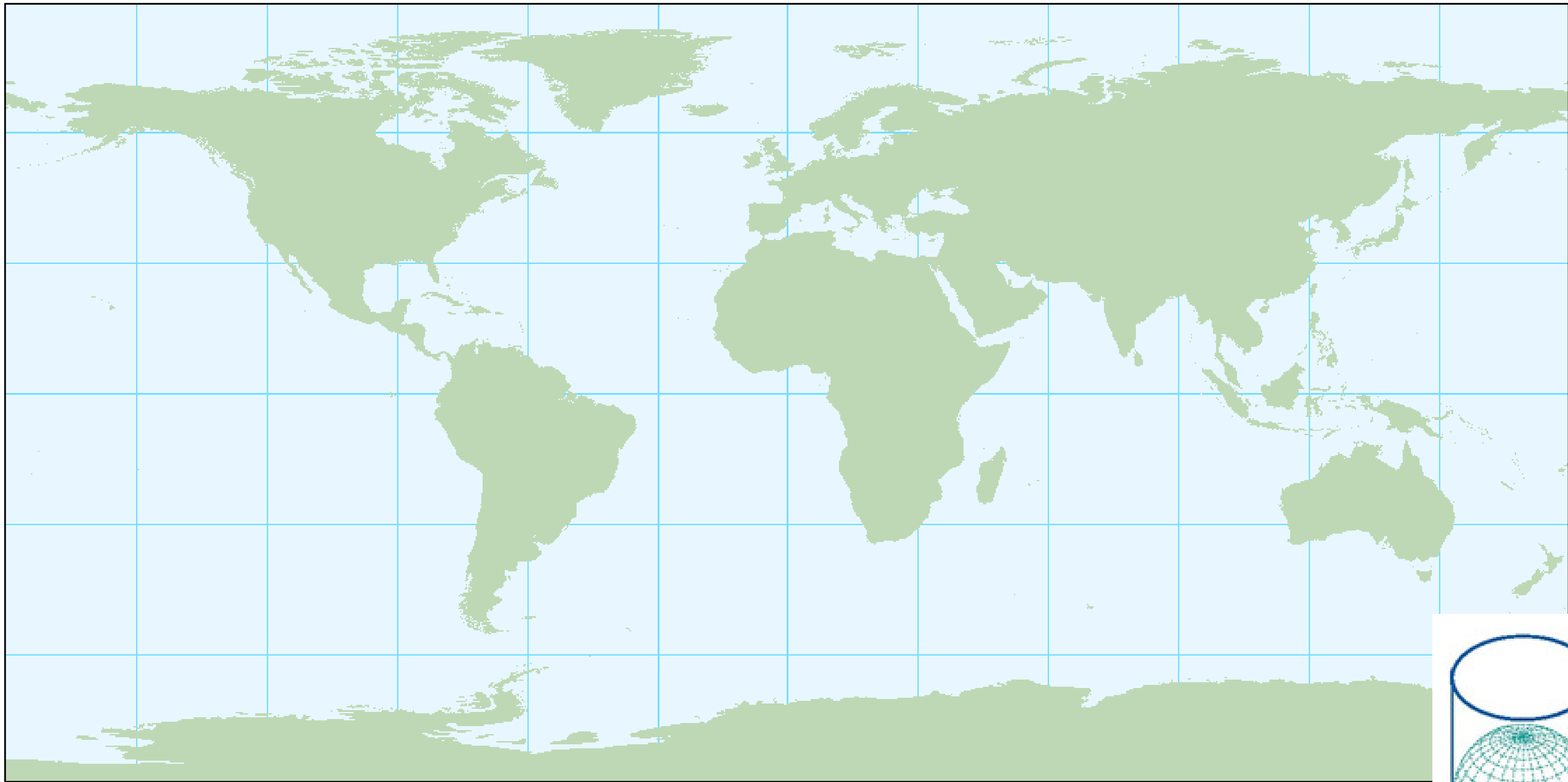
Cylindrical equal-area projection

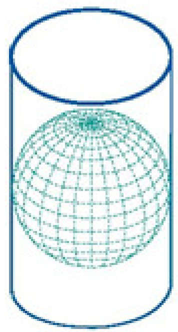


Areas are correctly represented



Equidistant cylindrical projection
(also called Plate Carrée)

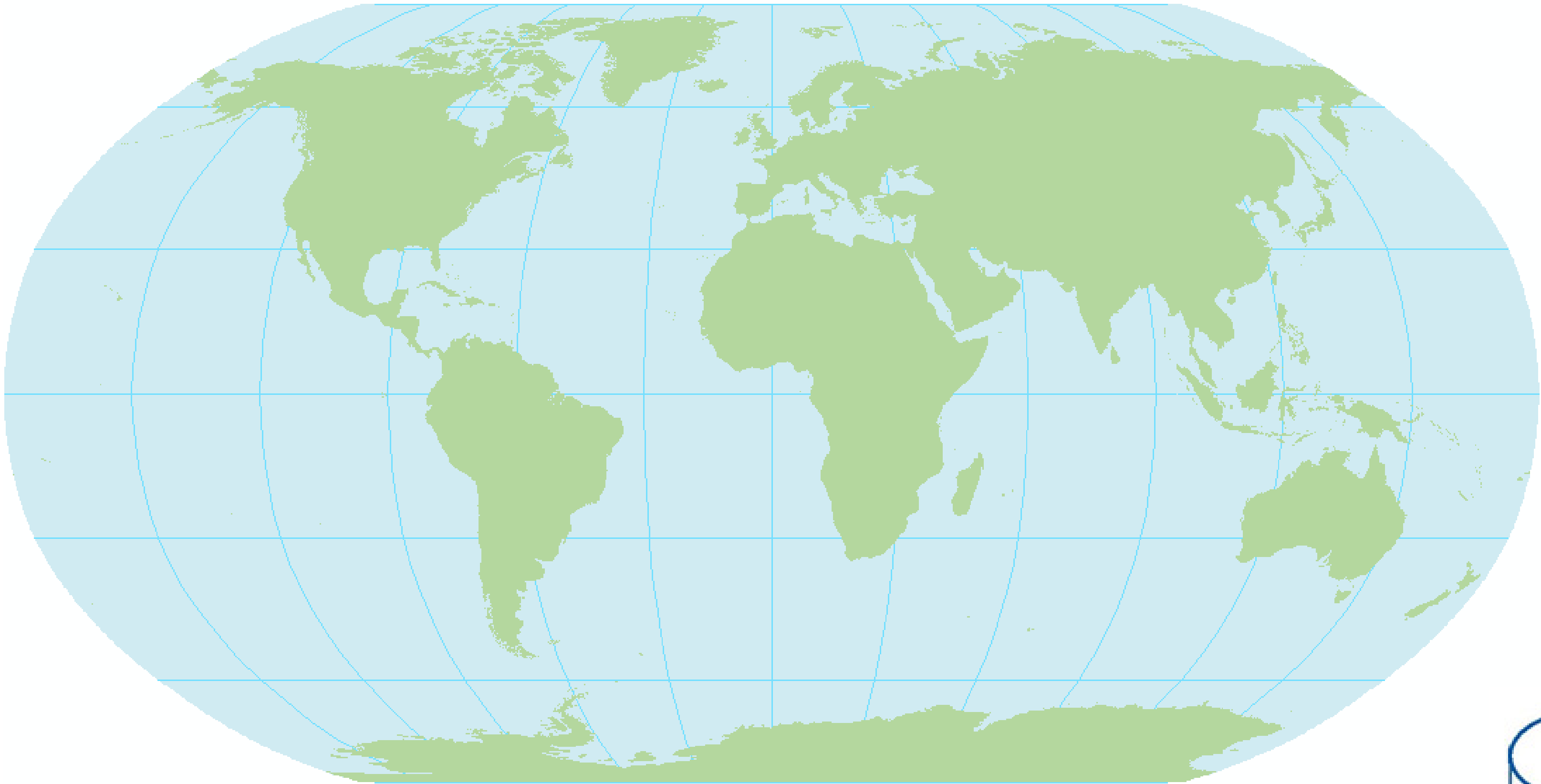




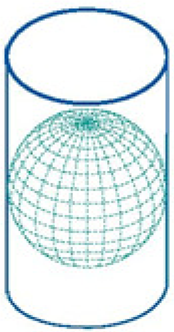
Equidistant along the meridians

Robinson projection

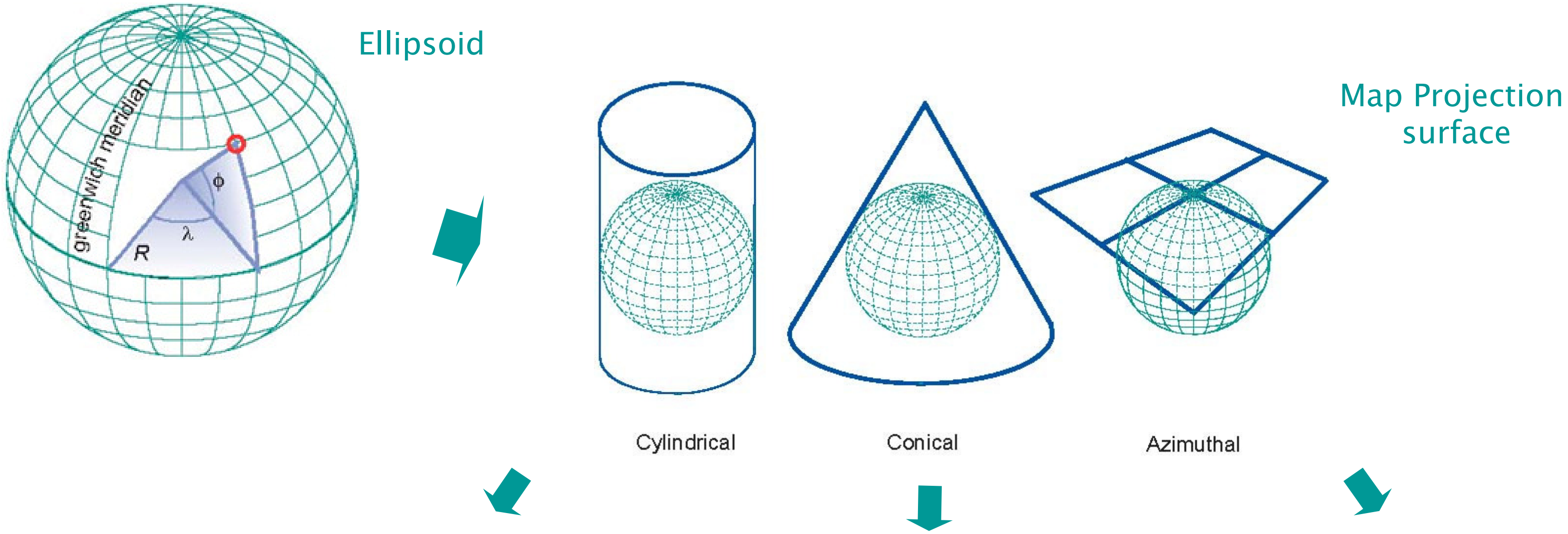
Pseudo-Cylindrical



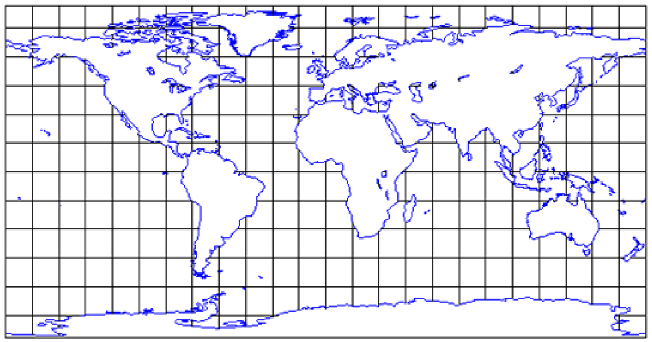
Neither conformal nor equal-area (both shape and area are reasonably well preserved)



Map projection class

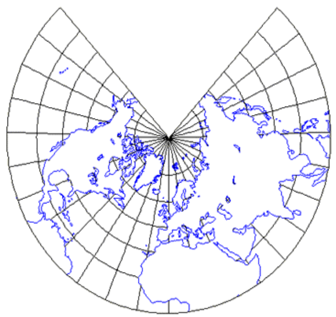


Cylindrical Projection



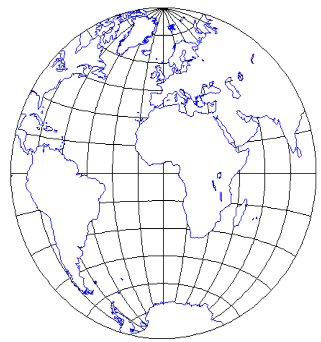
Mercator

Conical projection



Lambert Conformal Conical

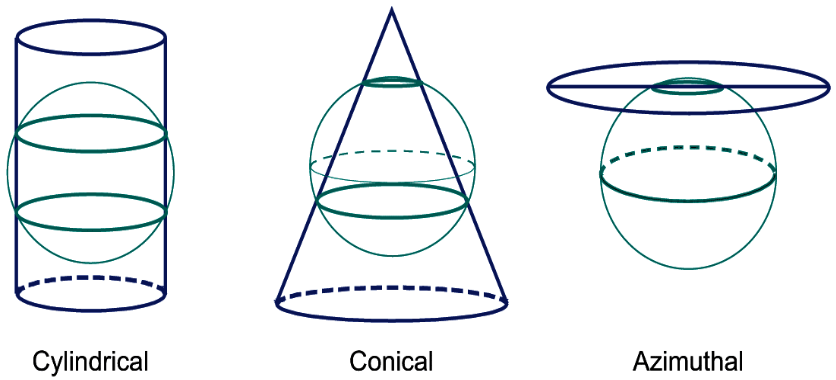
Azimuthal projection



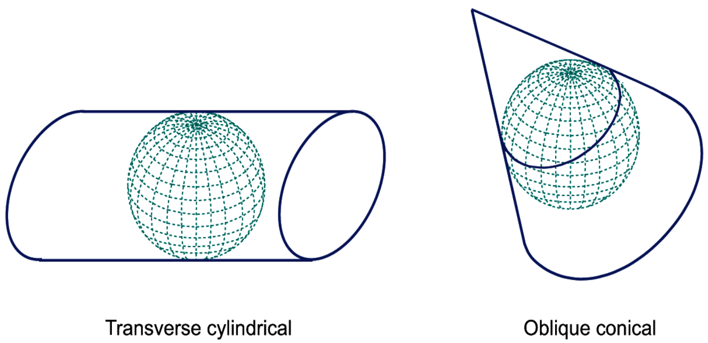
Stereographic projection

Classification of map projections

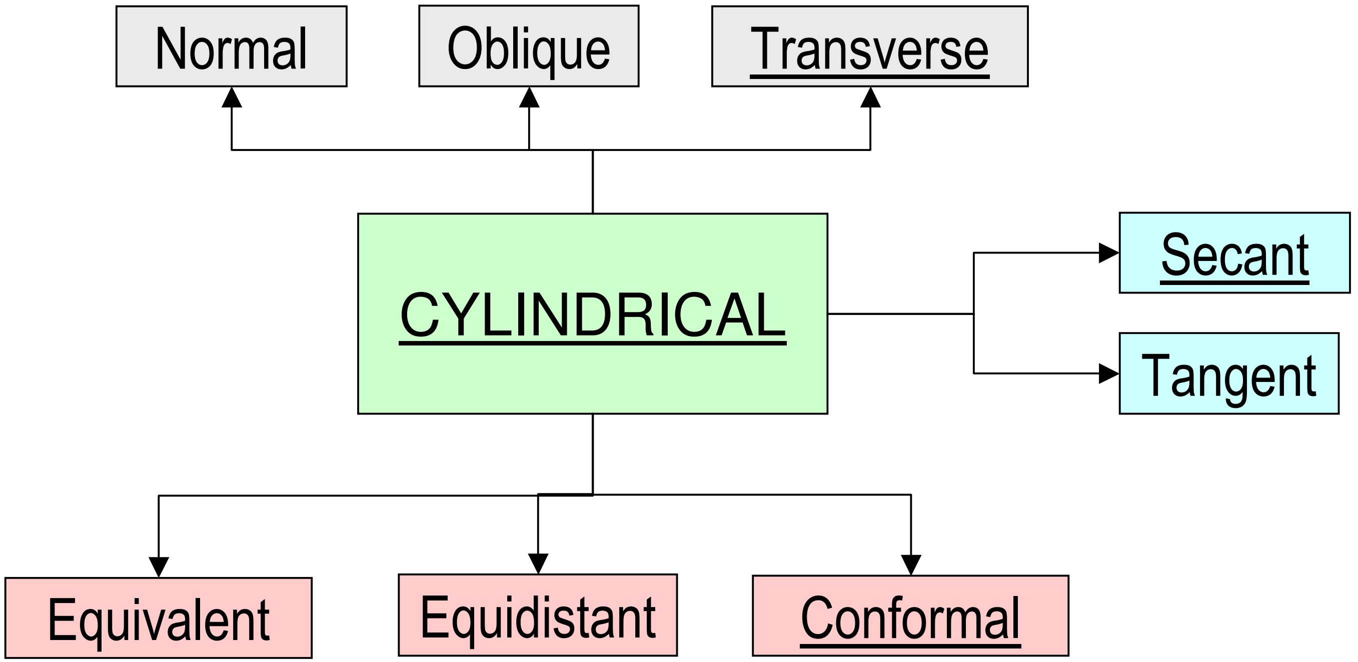
- Class
  - Cylindrical
  - Conical
  - Azimuthal
- Property
  - Equivalent (or equal-area)
  - Equidistant
  - Conformal
- Secant or tangent projection plane
- Aspect (orientation)
  - Normal
  - Oblique
  - Transverse



Secant projection planes

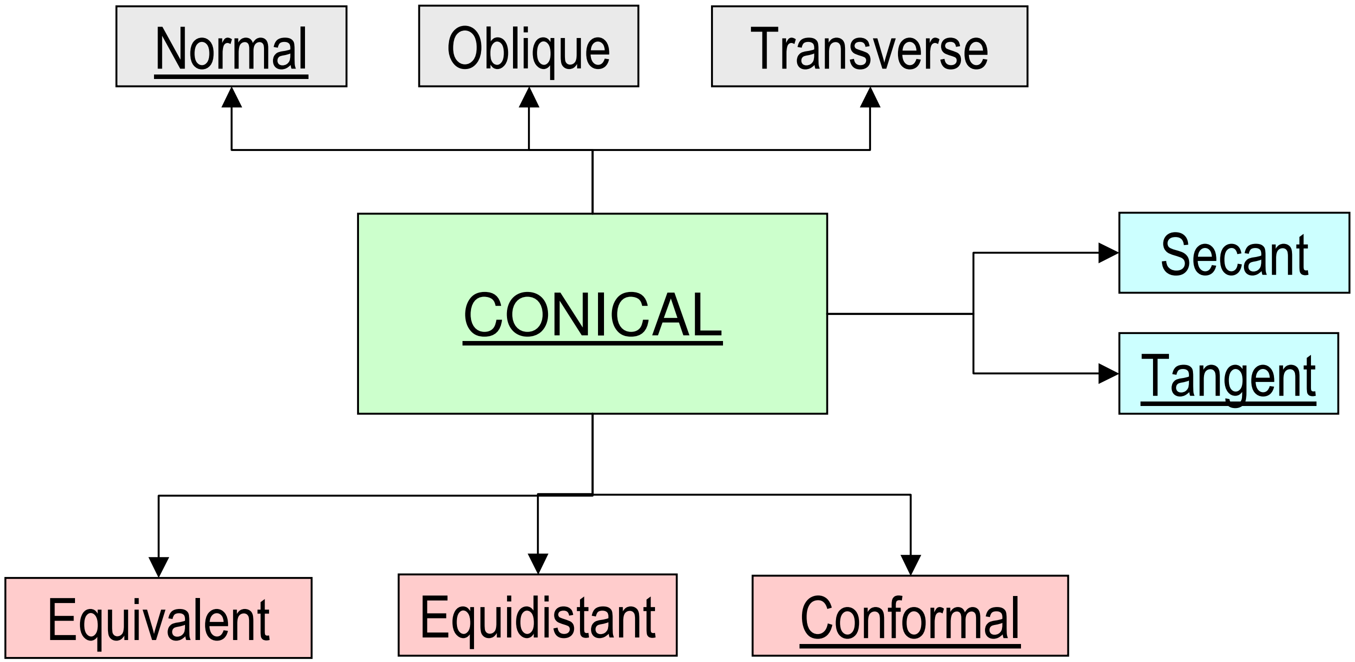


Classification of map projections



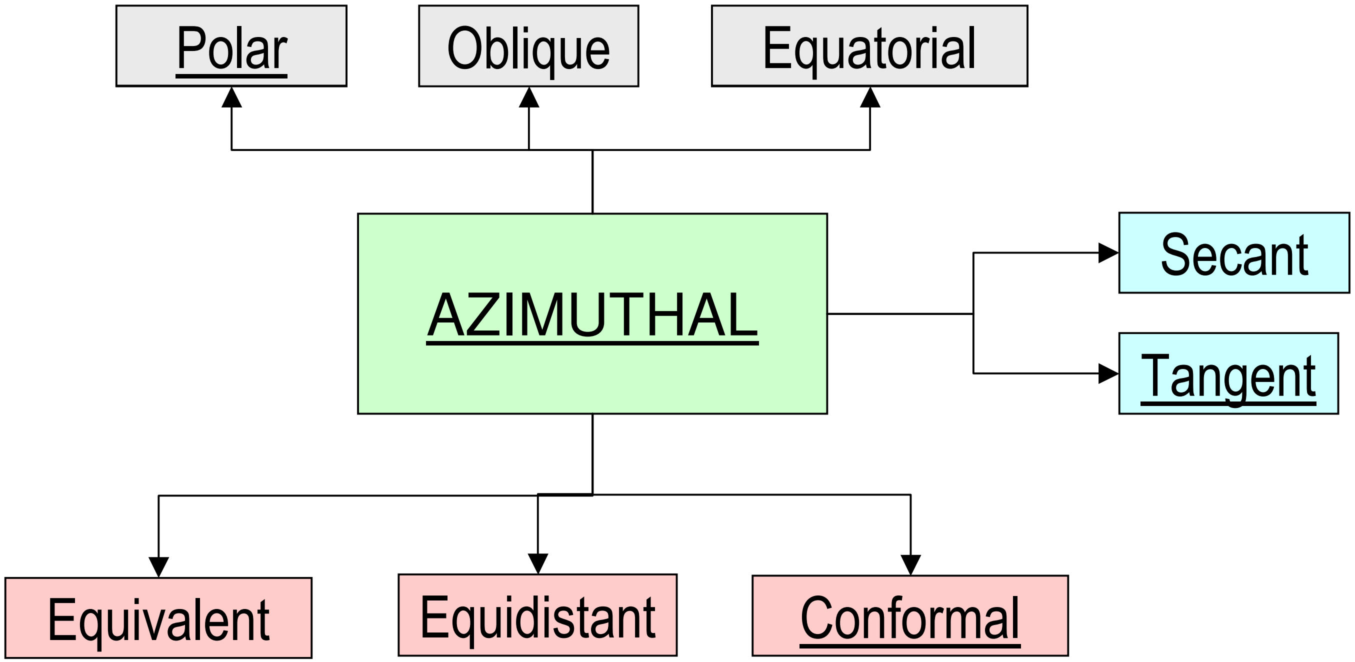
Conformal cylindrical projection with a transverse cylinder and secant projection plane (e.g. Universal Transverse Mercator)

Classification of map projections



Conformal conical projection with a normal cone and tangent projection plane (e.g. Lambert conformal conic)

Classification of map projections

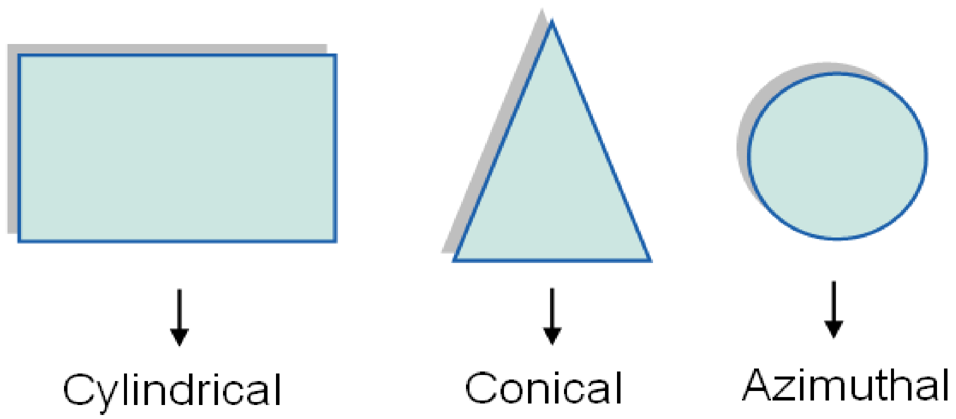


Conformal azimuthal projection with a tangent polar projection Plane (e.g. Universal Polar Stereographic)

Selection of a Map projection (I)

Normal *cylindrical projections* are typically used to map the World in its entirety. *Conical projections* are often used to map the different continents, while the normal *azimuthal projection* may be used to map the polar areas.

Also consider the shape of the area to be mapped:



Selection of a Map projection (II)

Conformal

Maps which require measuring angles (*e.g. aeronautical charts, topographic maps*)

Equivalent (or equal-area)

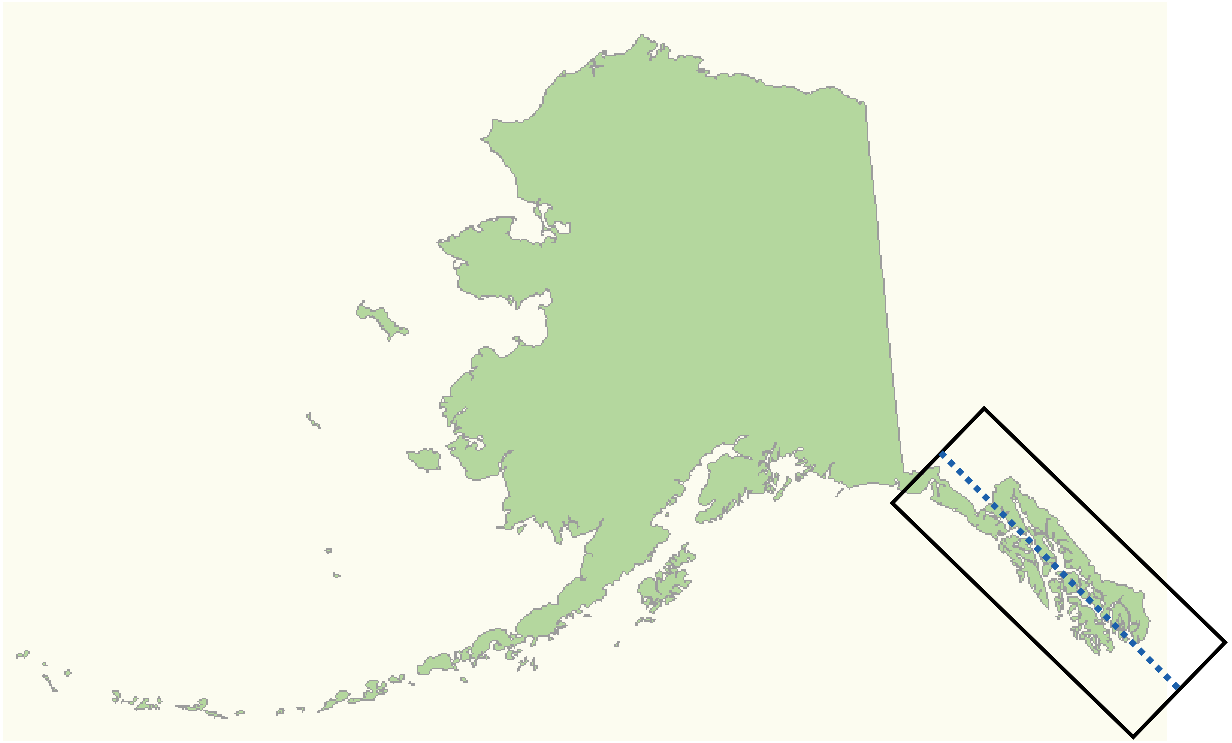
Maps which require measuring areas

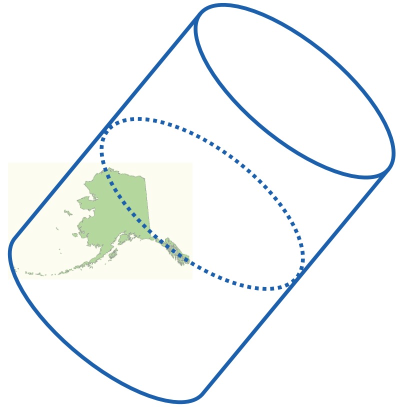
(*e.g distribution maps*)

Equidistant

Maps which require reasonable area and angle distortions *(e.g. several thematic maps)*

Selection of a Map projection (III)

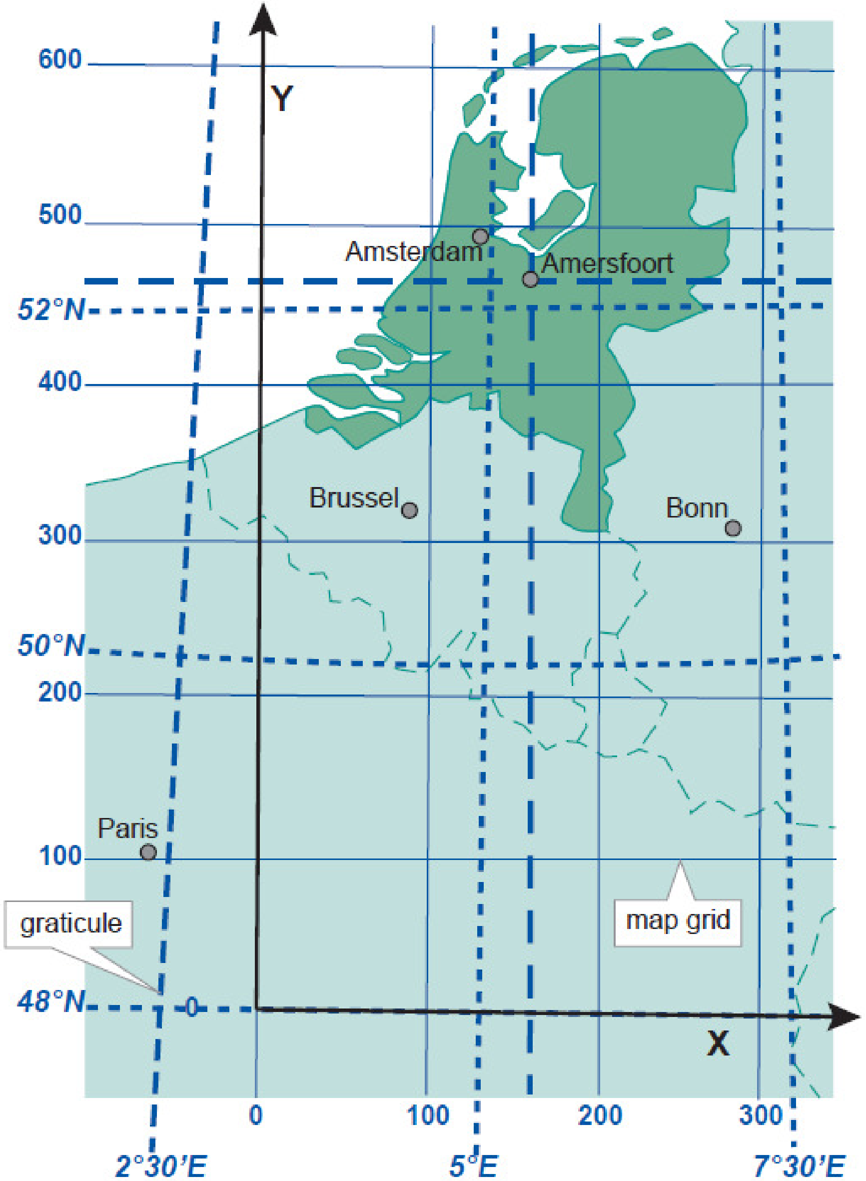




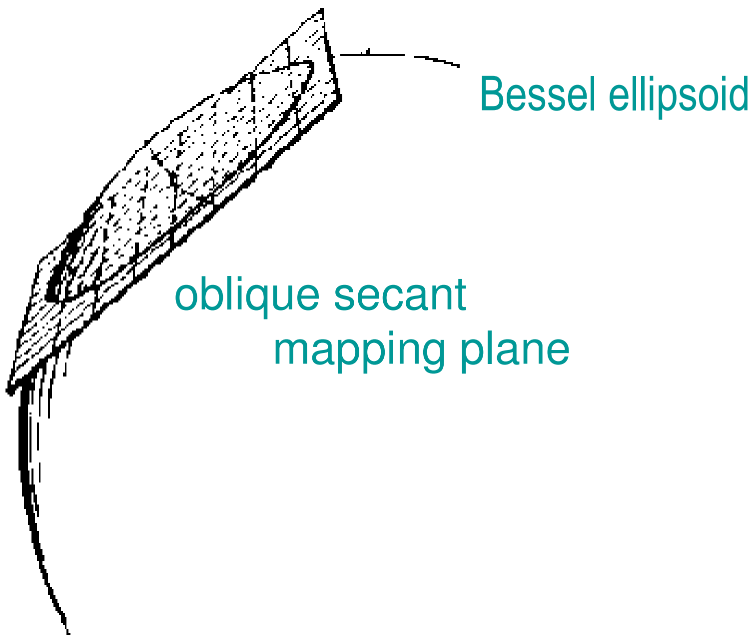
Oblique cylinder

The position (and orientation) of the projection plane is optimal when the projection plane is located along the main axis of the area to be mapped, or when the projection centre coincides with centre of the area.

Dutch map coordinate system



Projection: Stereographic
Geodetic datum: Amersfoort (Bessel ellipsoid)



Dutch RD system
(RijksDriehoekstelsel)

Universal Transverse Mercator

International Standard

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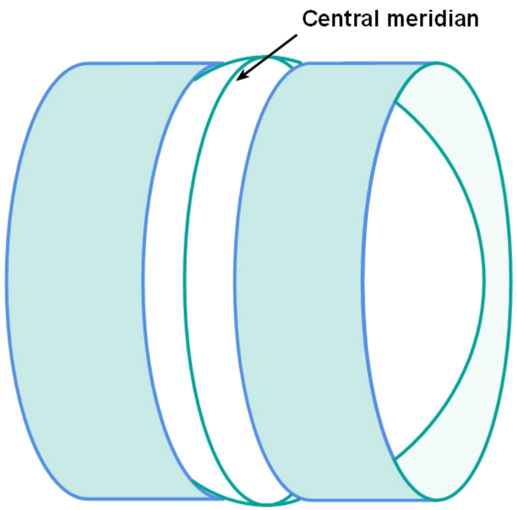
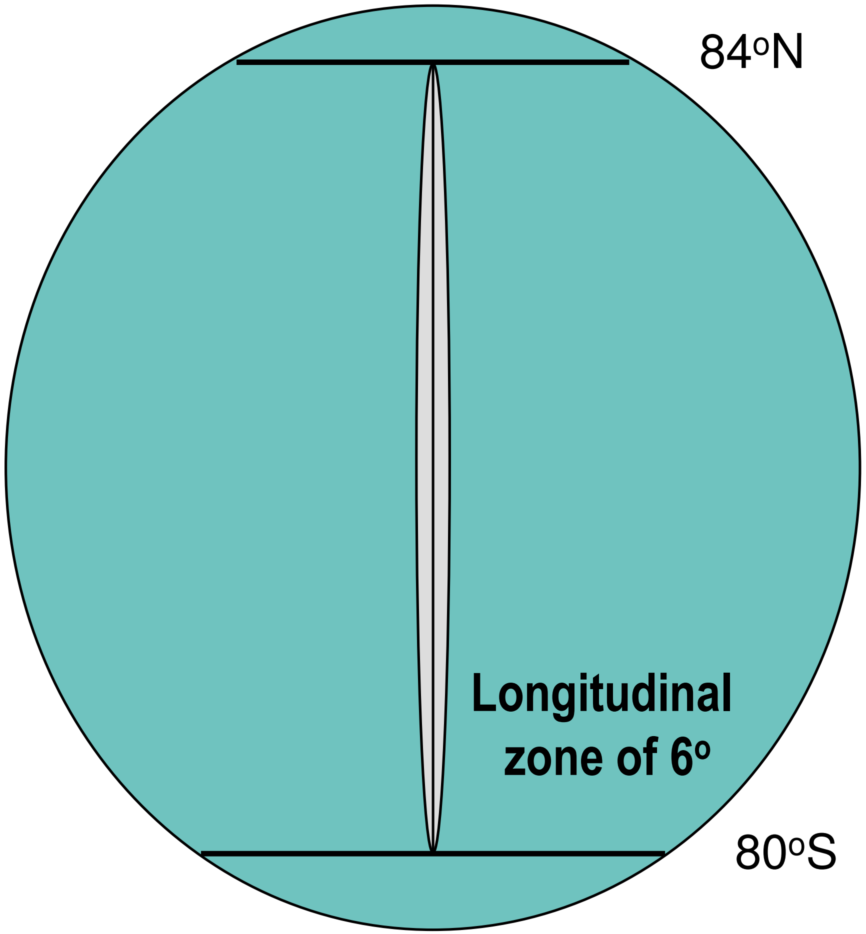
Universal Transverse Mercator projection

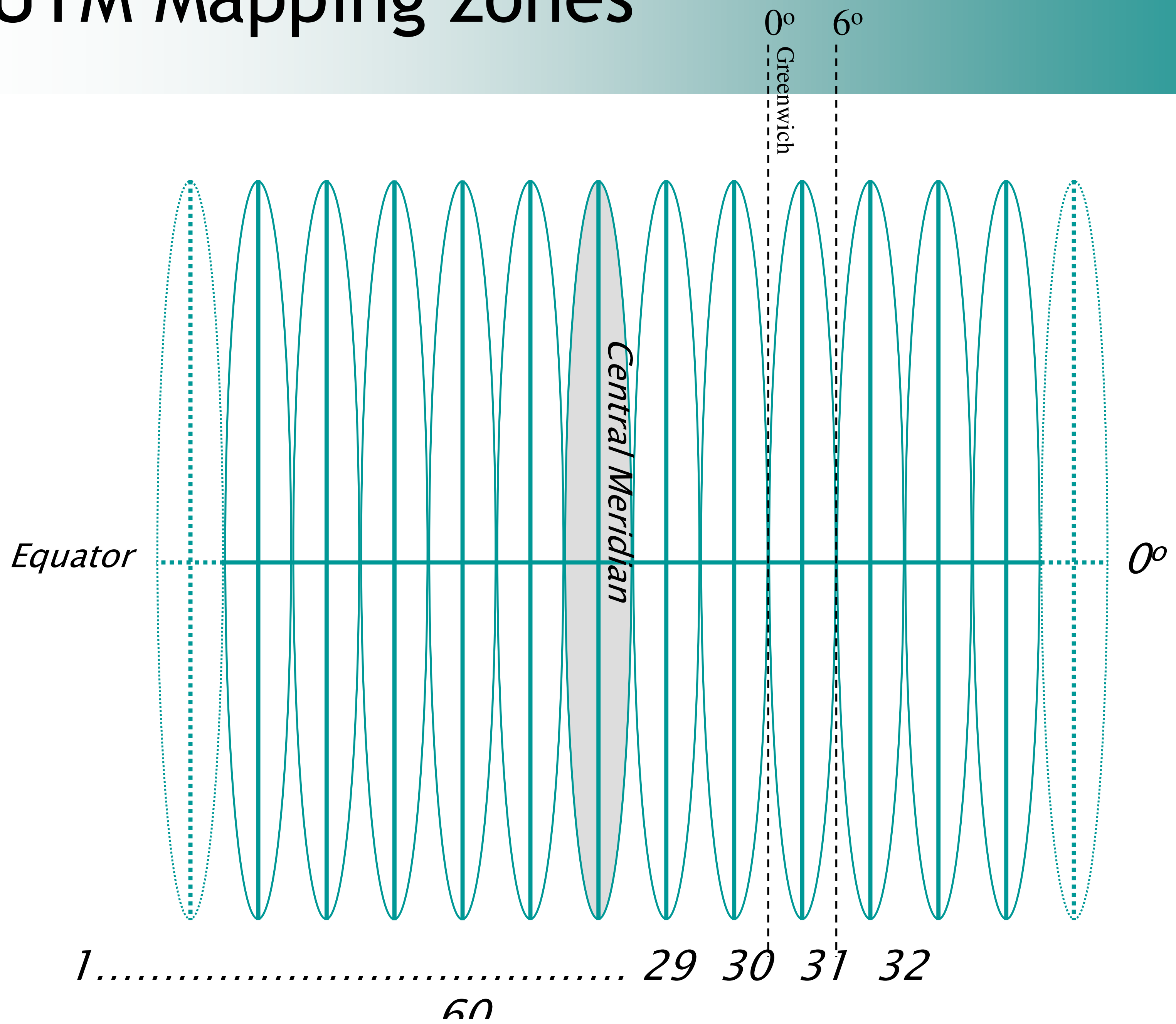


Conformal Cylindrical (transverse secant) projection

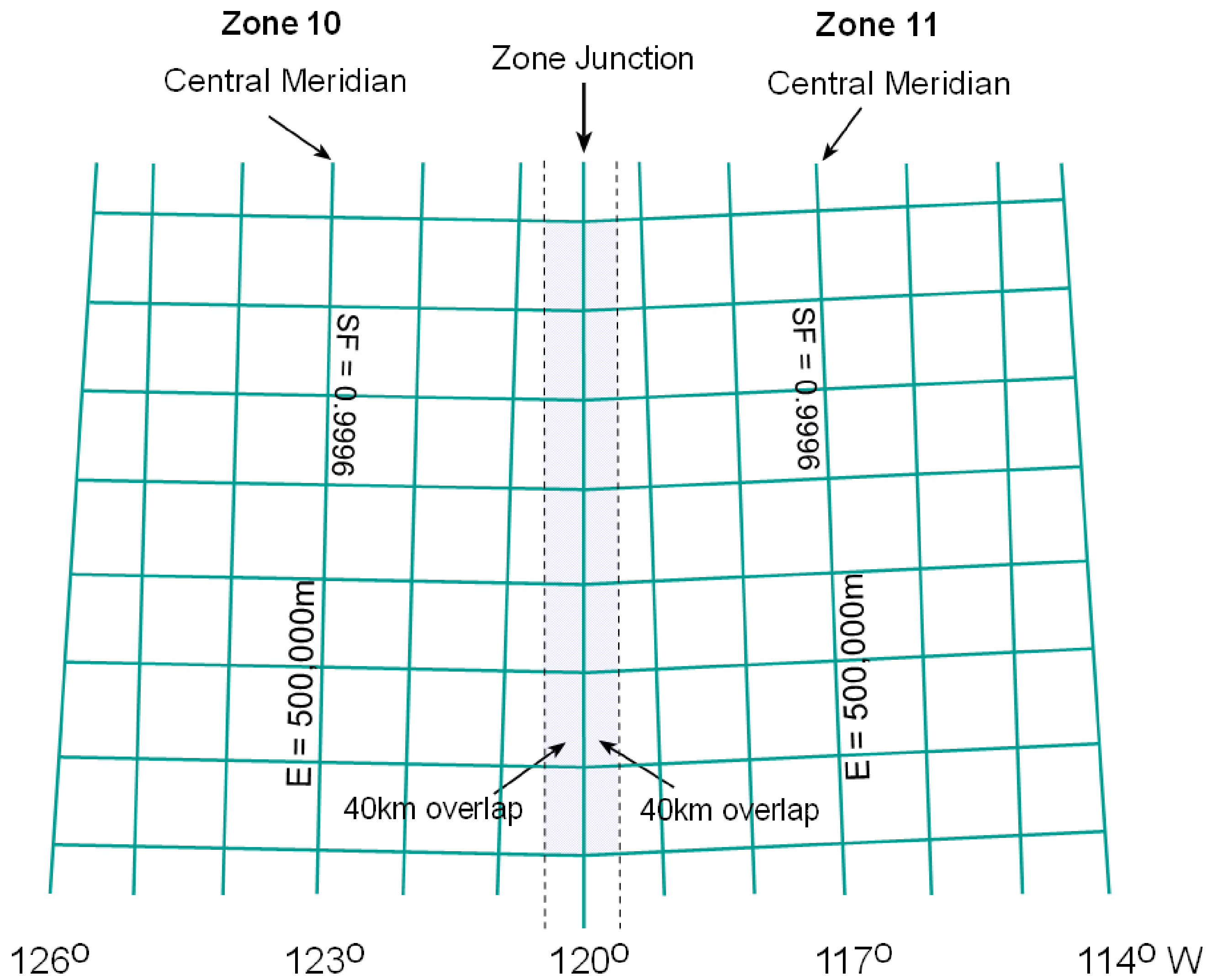
UTM Mapping zones



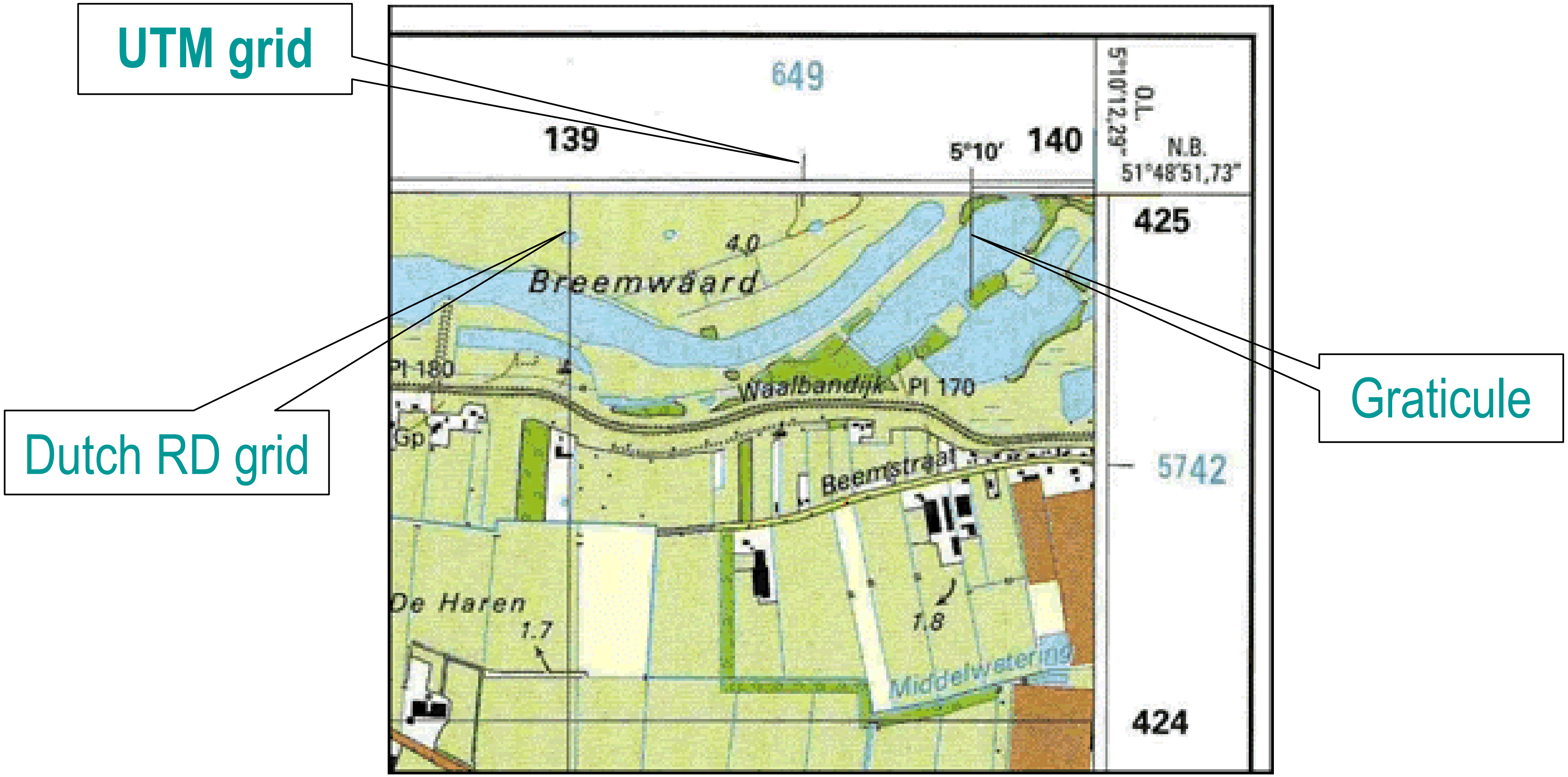
UTM Mapping zones



Two adjacent UTM zones



UTM grid on maps



Topographic map of the Netherlands (scale 1:25,000)

Coordinate transformations

Position City hall of Enschede

Position in Geographic coordinates:

- $\phi_{Amersfoort}$ = 52⁰ 13' 26.2"N $\lambda_{Amersfoort}$ = 6⁰ 53' 32.1" E

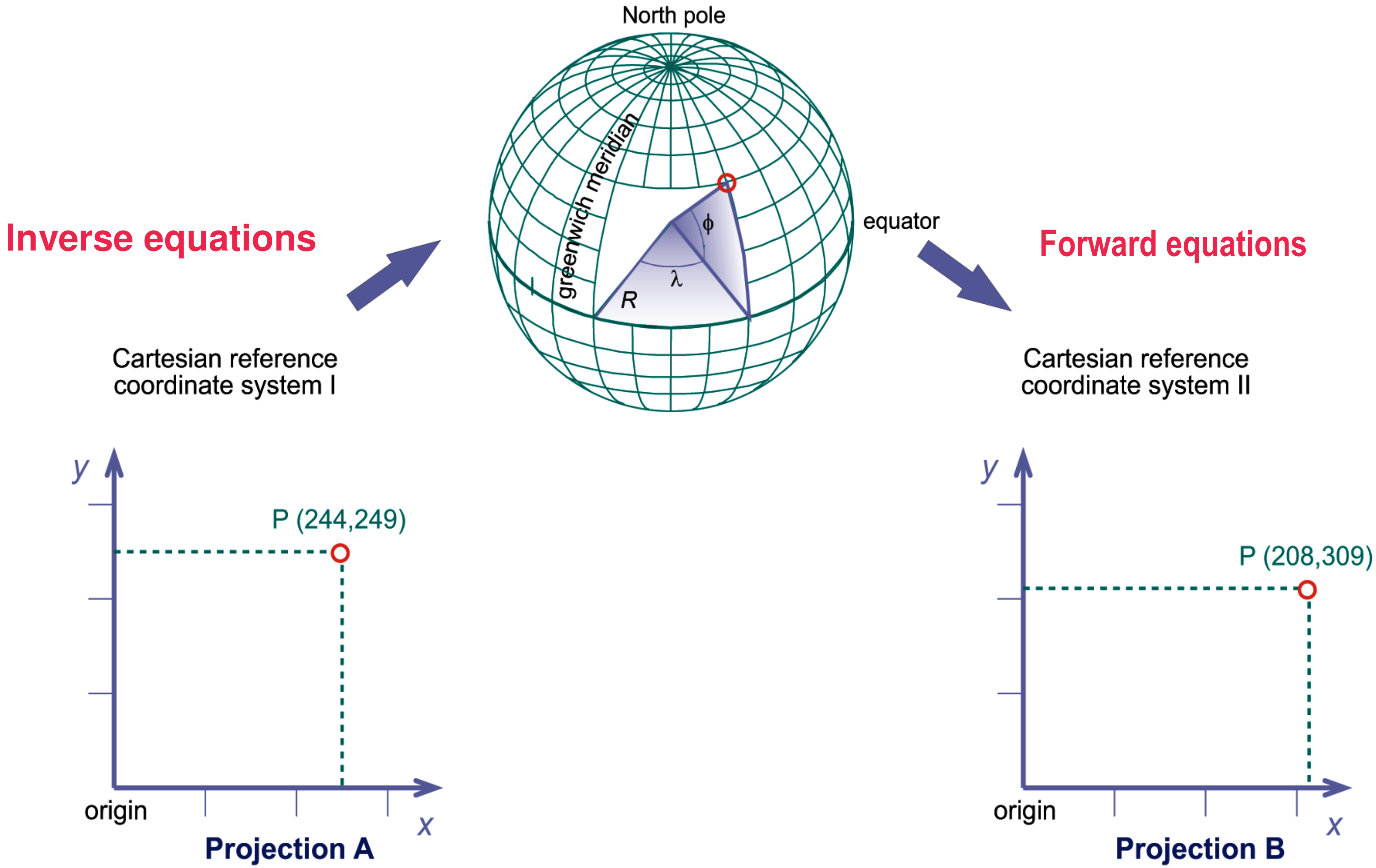
  (ϕ_{Bessel} = 52.223944⁰N λ_{Bessel} = 6.8922489⁰E)
- ϕ_{ETRS89} = 52⁰ 13' 22.6"N λ_{ETRS89} = 6⁰ 53' 29.7" E
- ϕ_{WGS84} = 52⁰ 13' 22.6"N λ_{WGS84} = 6⁰ 53' 29.7" E

Position in Map (plane rectangular) coordinates:

- $X_{Dutch\ RD}$ = 257790.12m $Y_{Dutch\ RD}$ = 471607.17m (Old RD1918)
- $X_{Dutch\ RD}$ = 257776.47m $Y_{Dutch\ RD}$ = 471588.14m (New RD)
- X_{UTM31} = 765872.57m Y_{UTM31} = 5793185.04m
- X_{UTM32} = 356065.01 m Y_{UTM32} = 5788133.6m

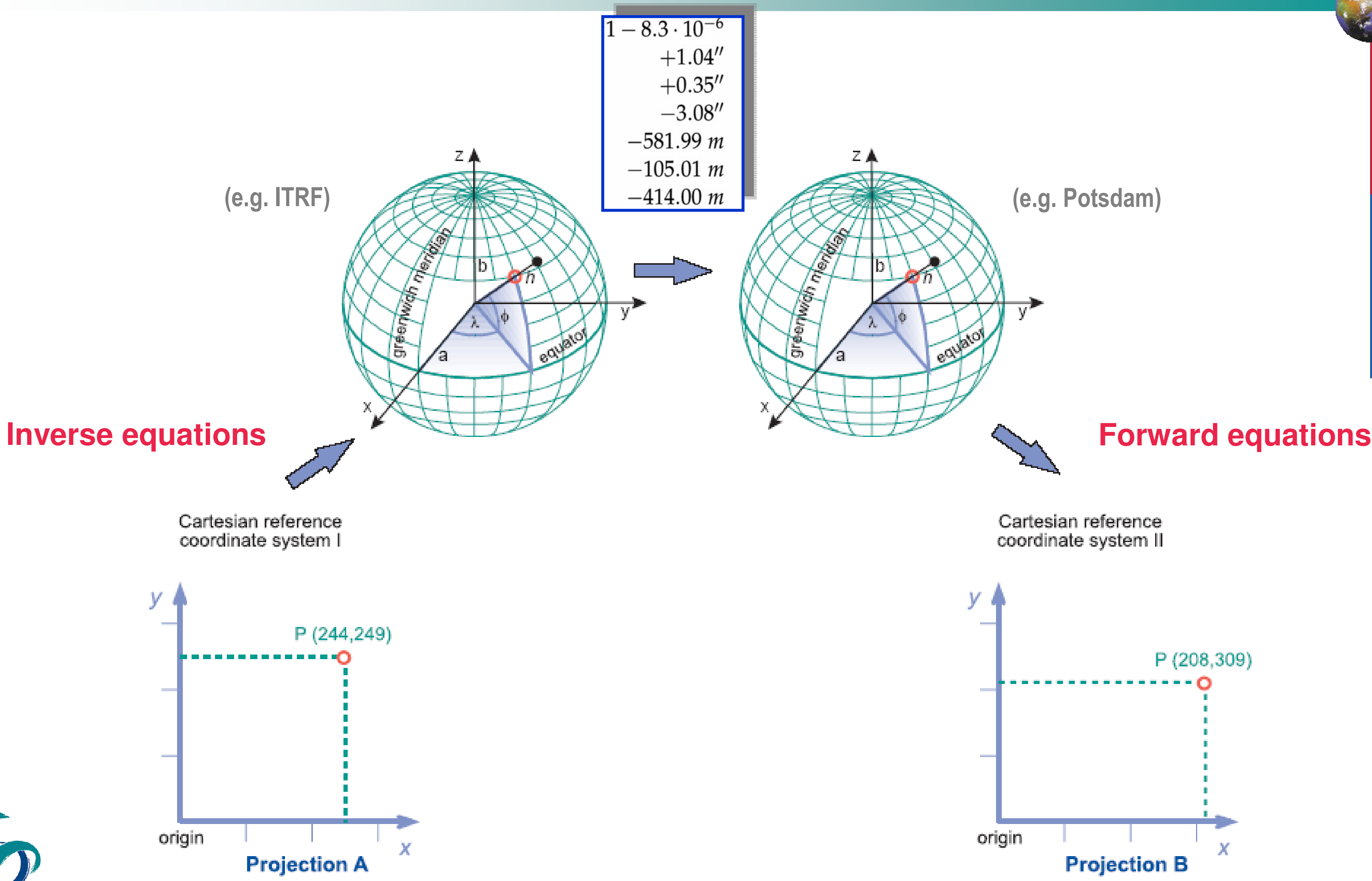
Map projection change

Using projection equations

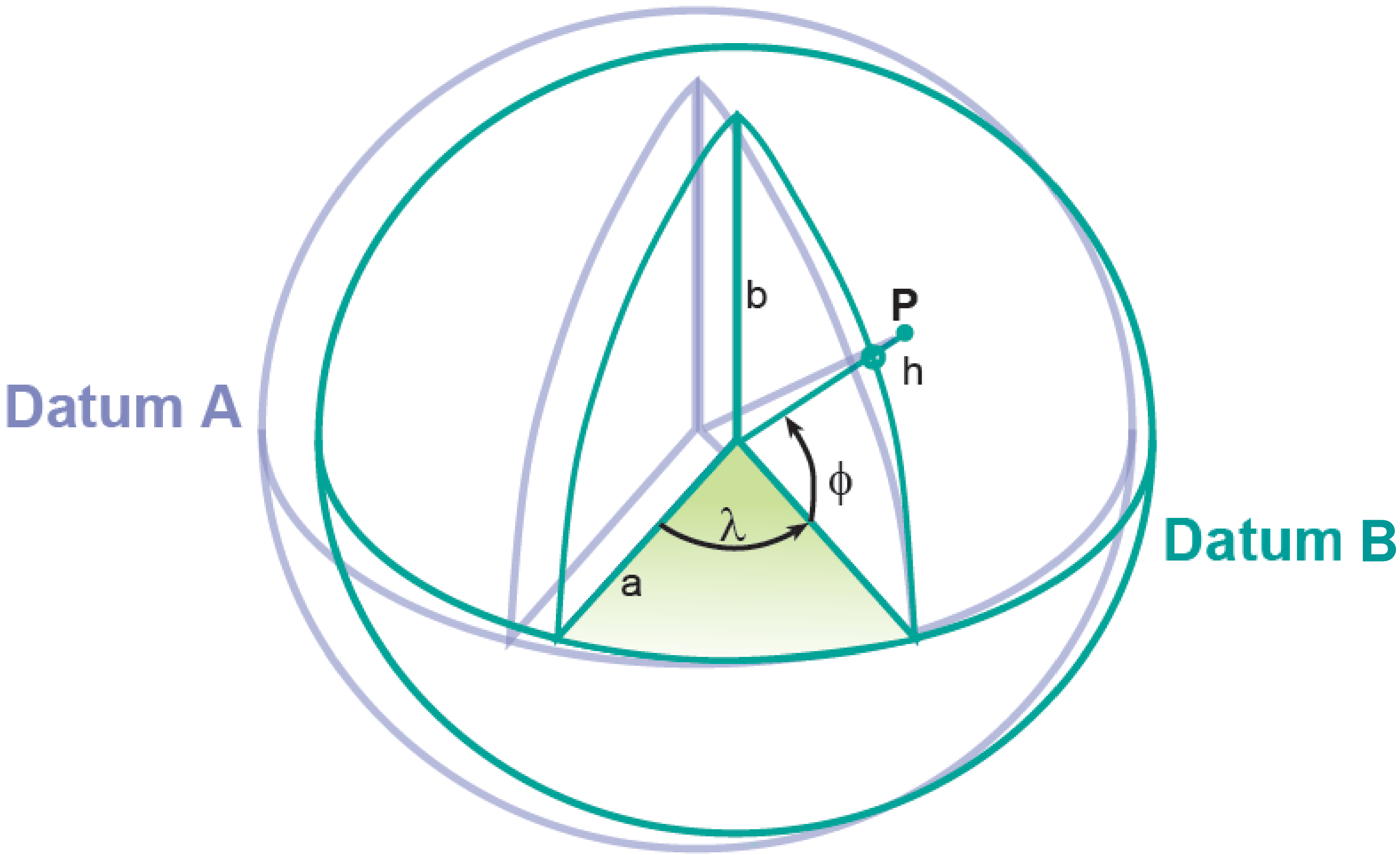


Map projection change

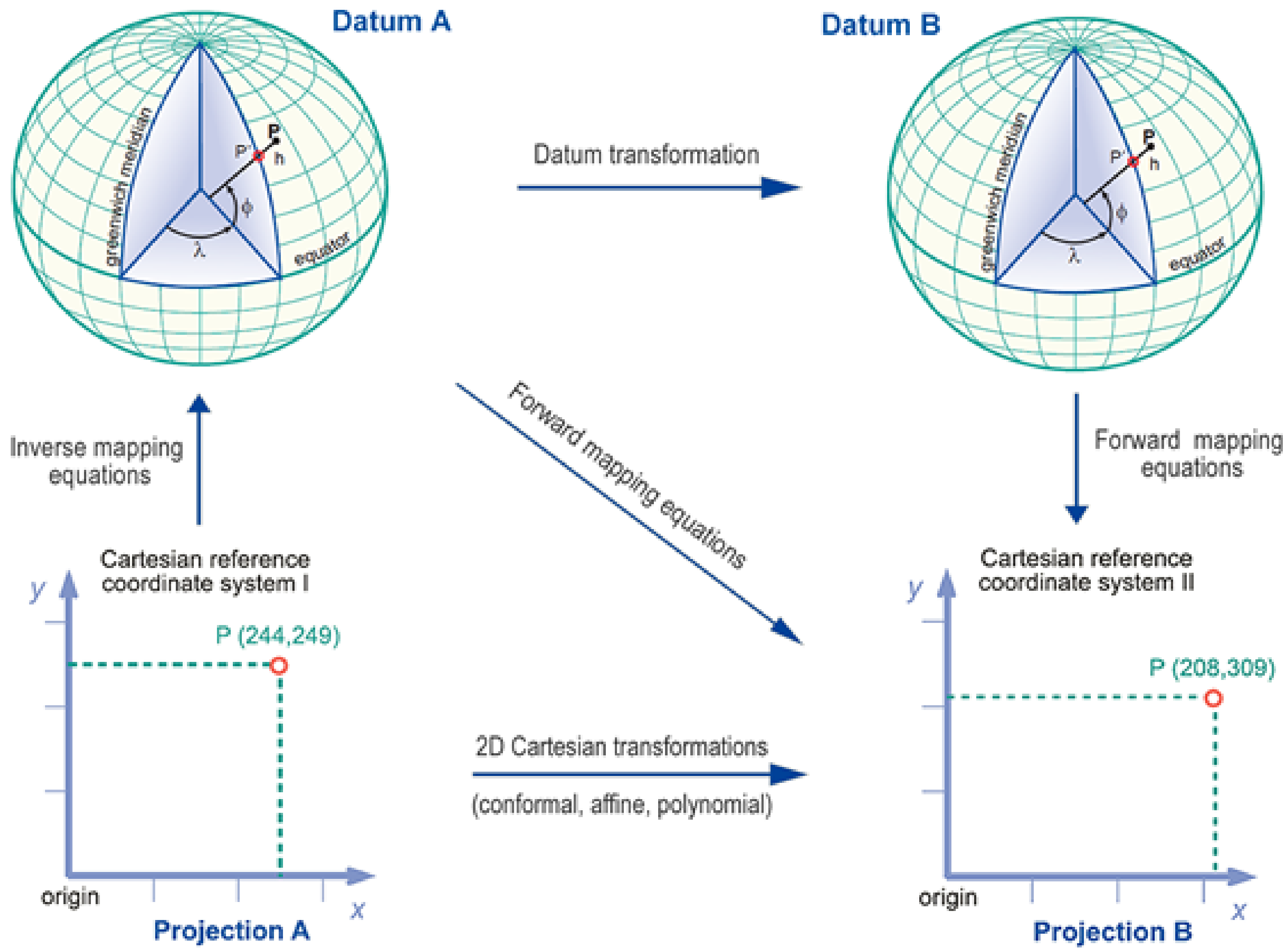
Including a datum transformation



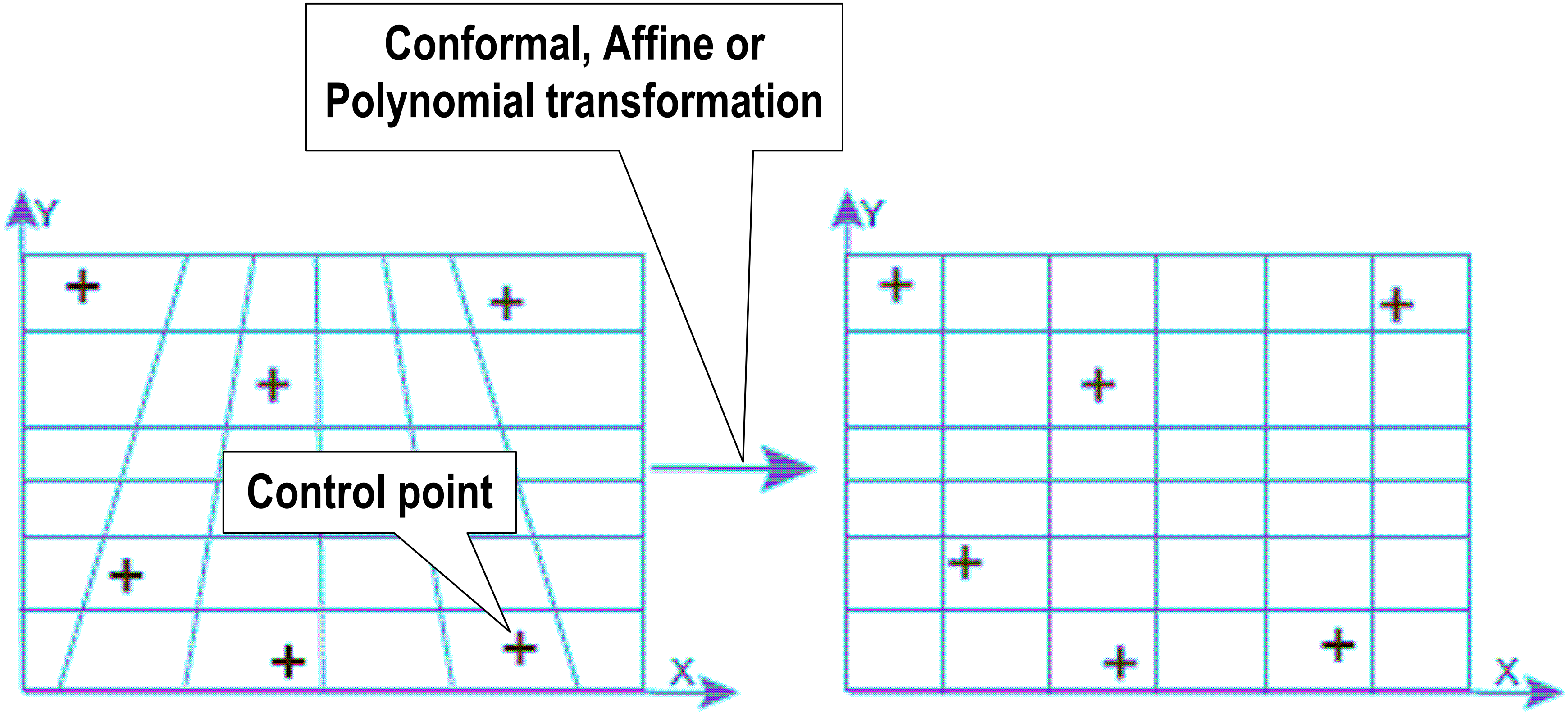
Datum shifts



Coordinate transformations (overview)



Projection change using a 2D Cartesian transformation

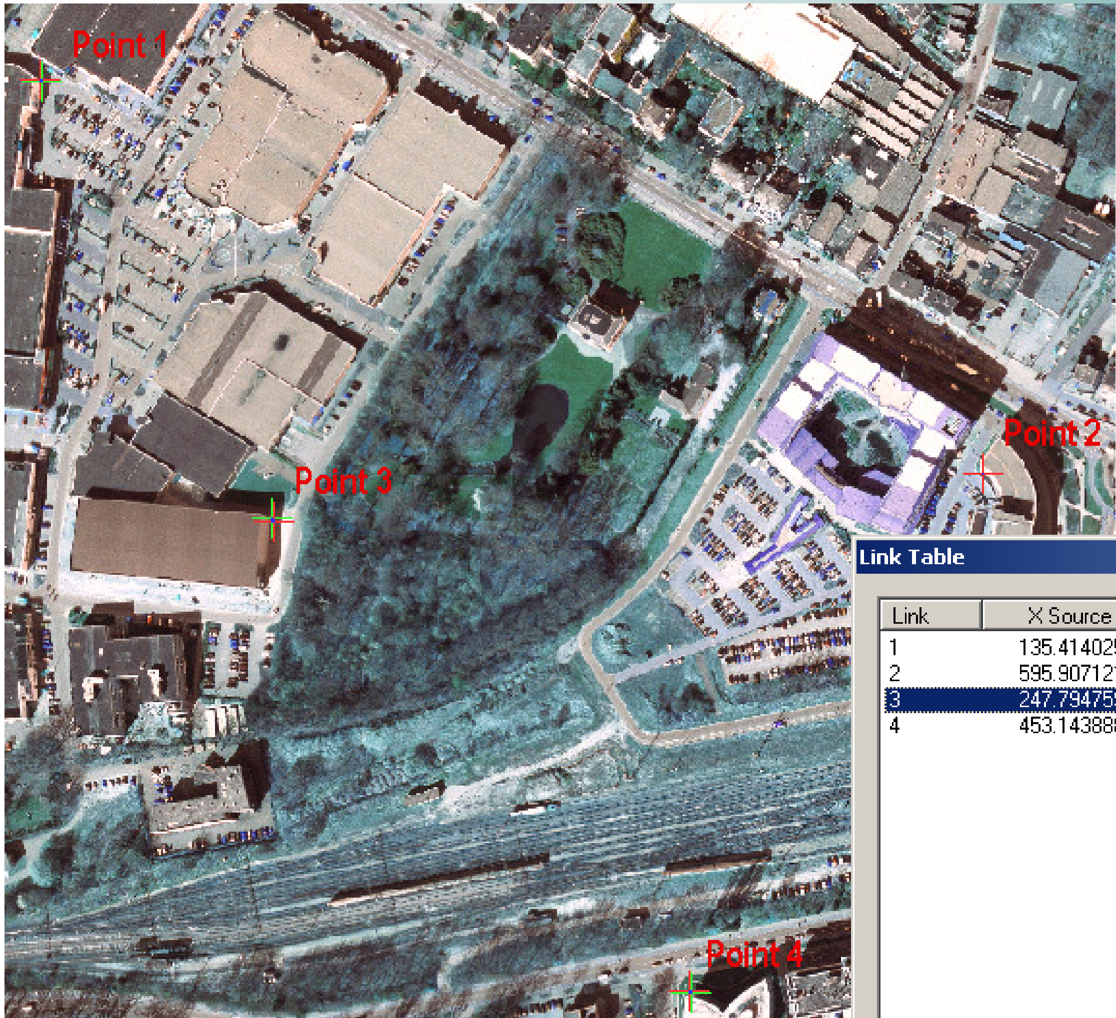


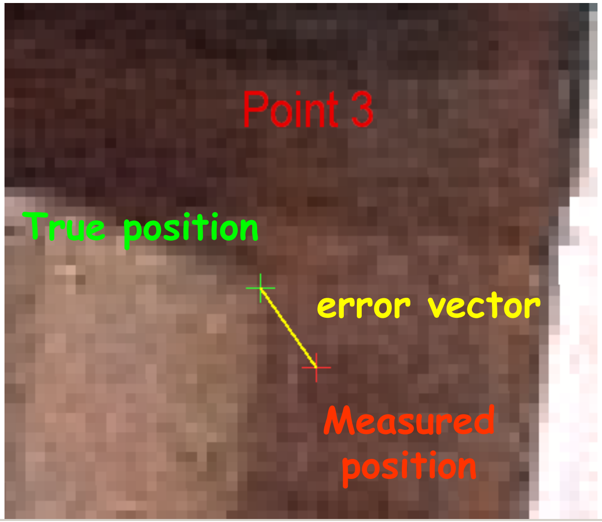
Projection unknown

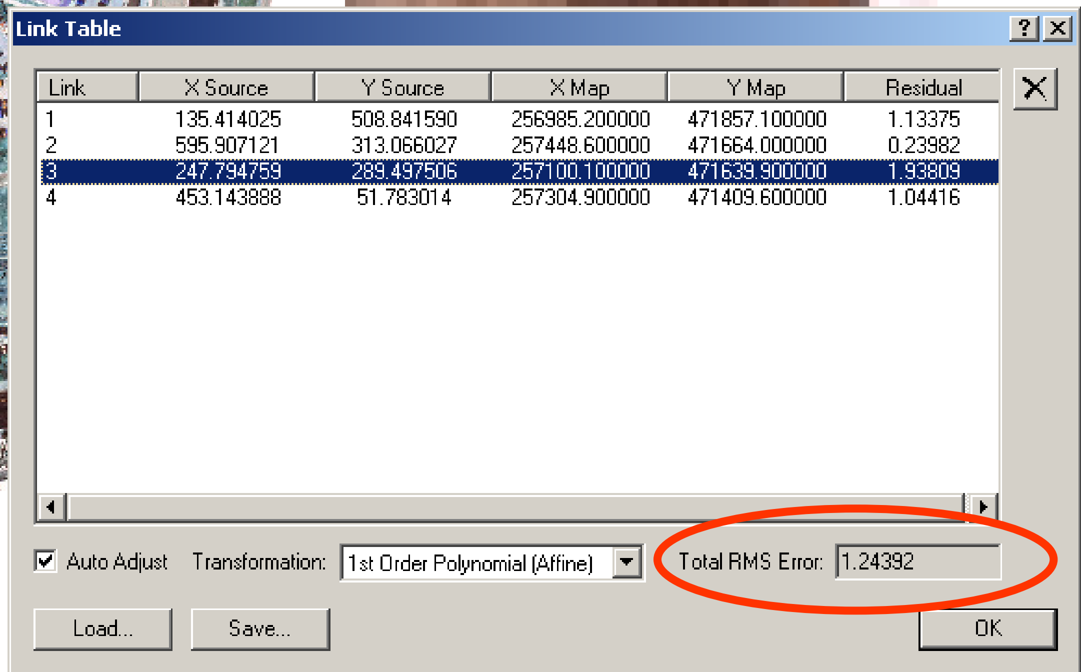
Projection B

The unknown coordinate system is related to a known coordinate system on the basis of a set of known points

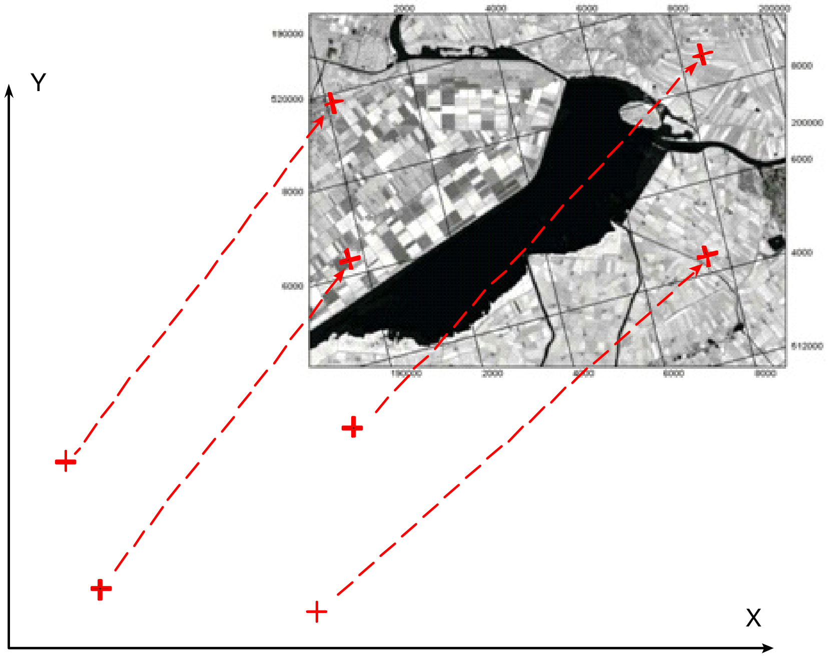
Application: Image Rectification (I)





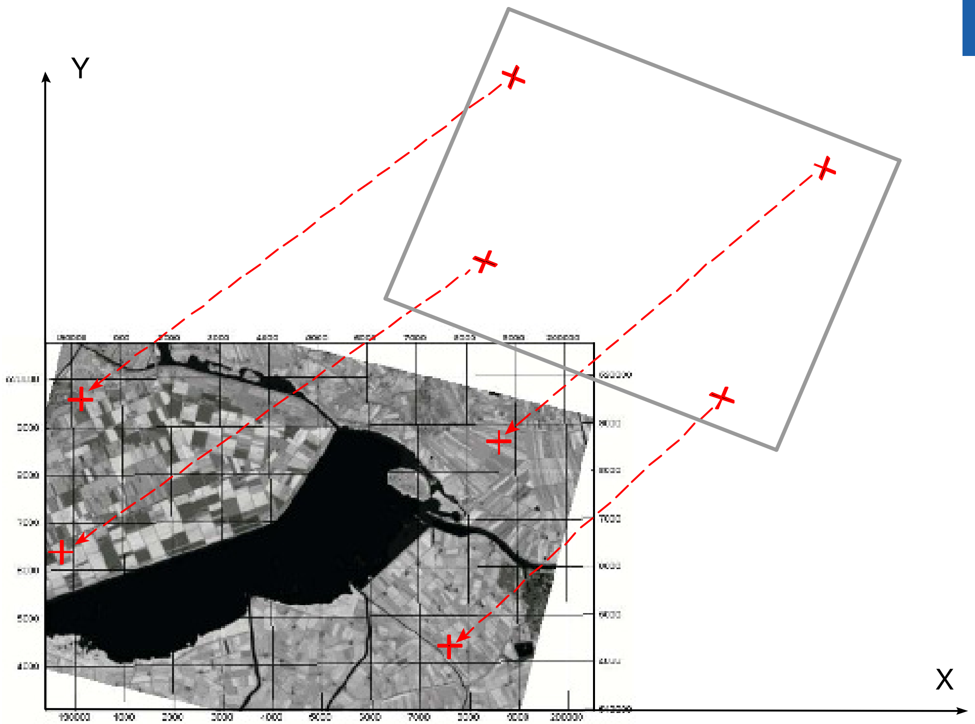


Application: Image Rectification (II)



Georeferencing

Image Rectification (geocoding)



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Application: Matching data layers

Thank you!