Reference systems for geographic information

Spatial Data Analysis and Simulation modelling, 2020

Simon Scheider, Department of Human Geography and Planning, Utrecht

Outline

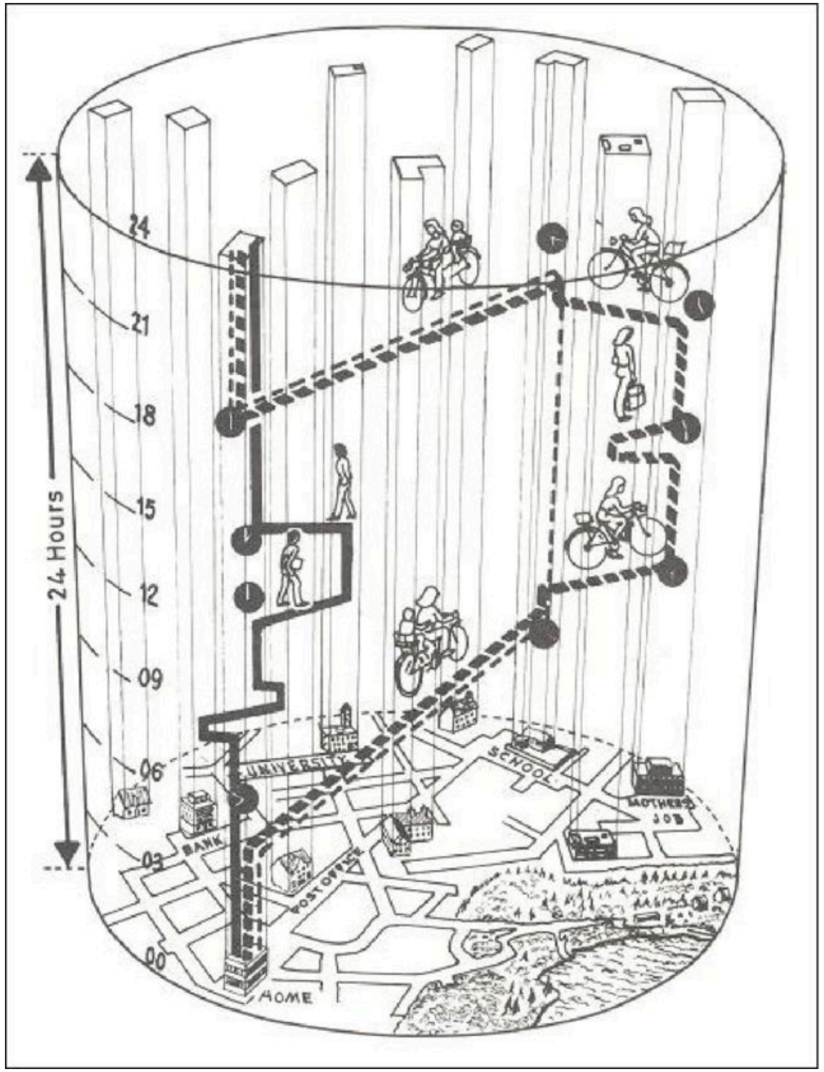
- Components of geographic information
- Reference systems
- … for attributes
- … for time
- Coordinate reference systems (CRS)
    - Datums
    - Geographic coordinates
    - Map projections
- EPSG standardization
- CRS Transformations

Components of geographic information

… geographic information commonly broken into:

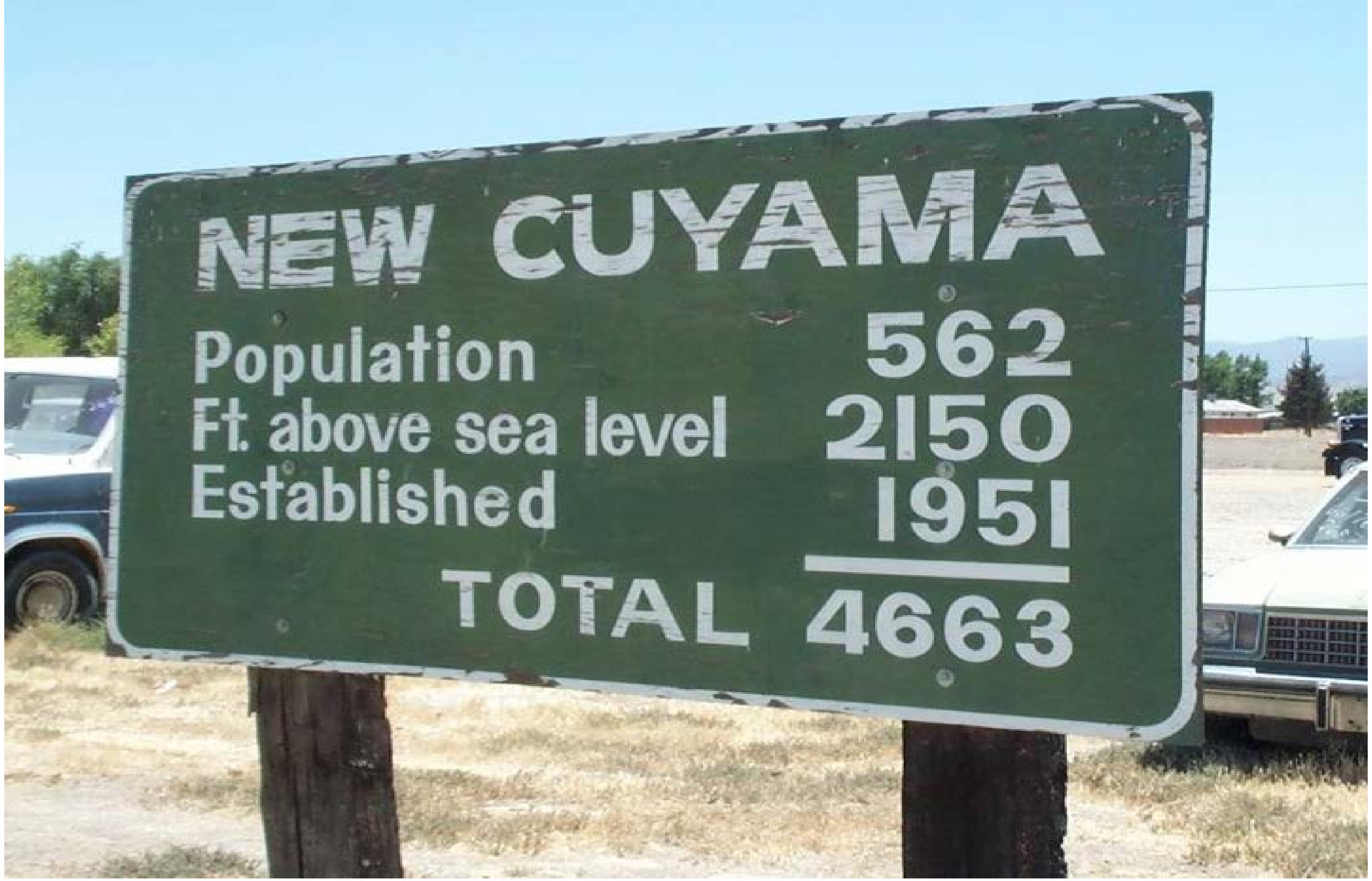
1. 2 (or 3) dimensional **spatial** component (here: horizontal plane)
2. An (often implicit) **temporal** component (here: z axis)
3. A **thematic** component (here: symbology)

How are these components measured?



Space-Time Diagram by Parkes and Thrift (1980)

Reference systems



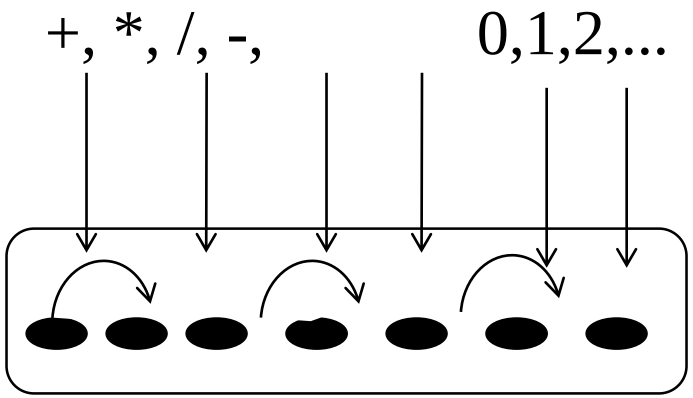
Reference systems

- Established set of rules for measurement of phenomena and their relations
- Constrains inter-subjective interpretation and **reference** to these phenomena
- In this way, measurement symbols obtain an **inter-subjective meaning** and **become reproducible**
- Reference systems **constrain operations** one can apply to data
- Adding up values requires the same reference system!

Attribute reference systems

- Interpretations of signs into a domain of measurement
- For example, interpretation of “1” into a length (meter)
- Fixed by convention (think about the prototype meter)

For example: Meter scale for measuring lengths and distances



Terms (relational symbols, numbers)

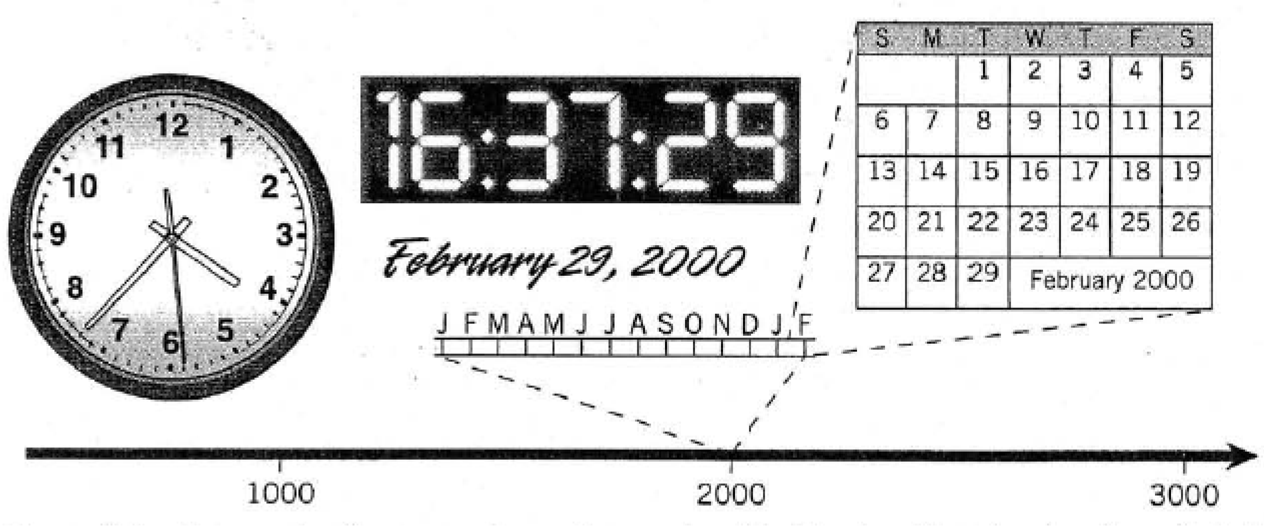
Interpretation / Convention

Domain

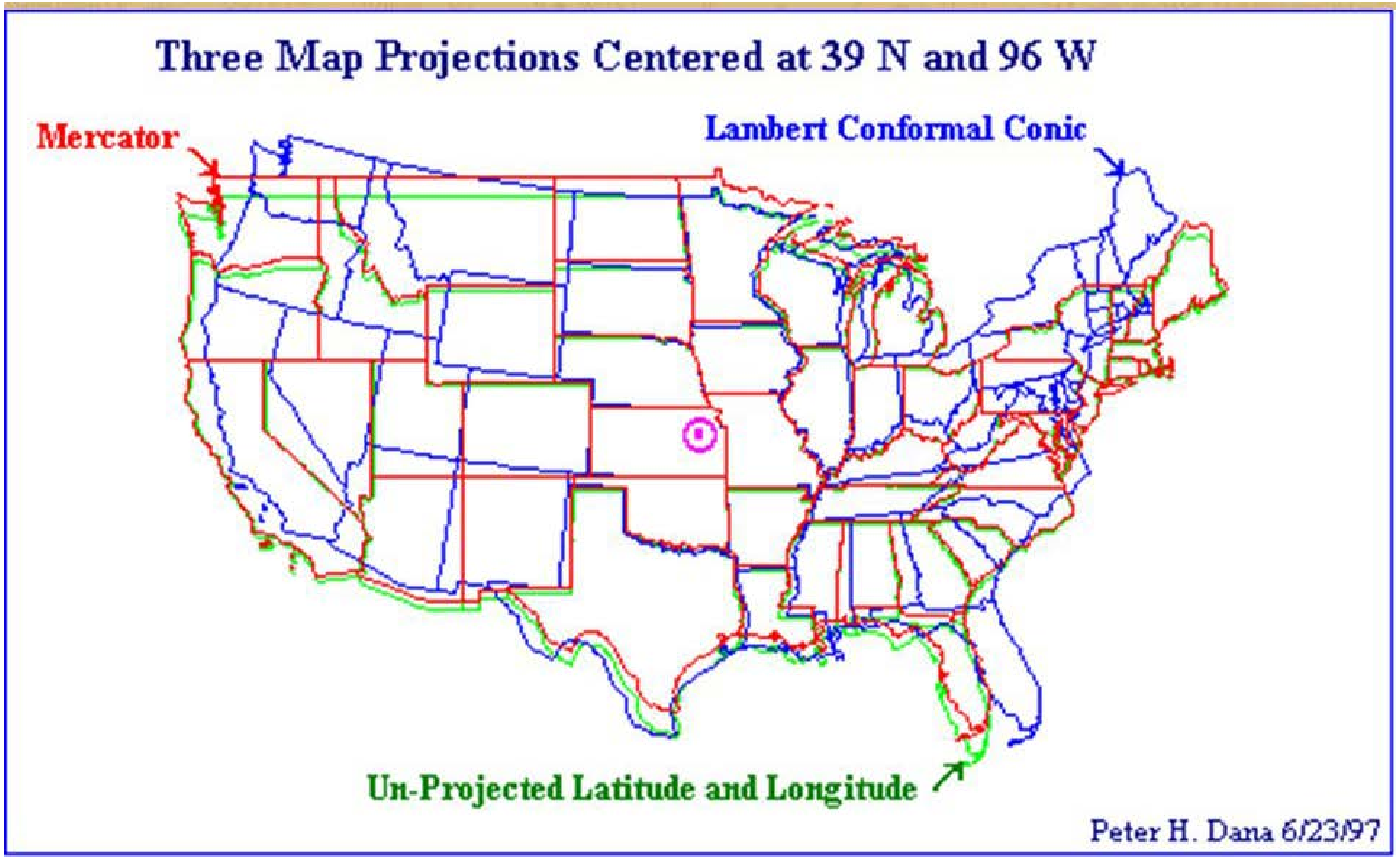
Temporal reference systems

- Can be linear (e.g. “Unix time” seconds since 1 January 1970)
- … or circular (weekdays, months, hours of a day, …)
- *ISO 8601 Data elements and interchange formats*, based on Gregorian calendar (Greenwich Mean Time)
- Forms the basis of *xsd:dateTime:*

```
[-]CCYY-MM-DDThh:mm:ss[Z|(+|-)hh:mm]
```

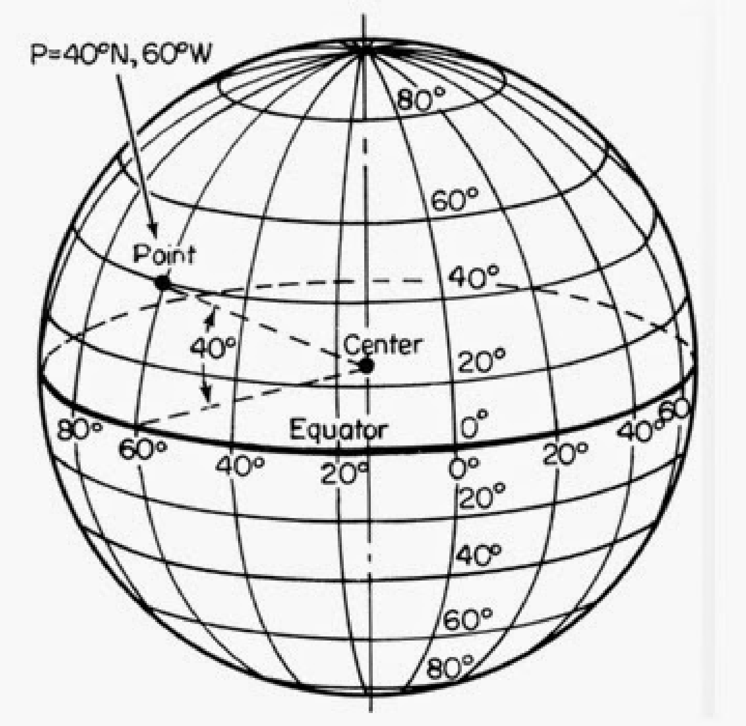


Coordinate reference systems (CRS)



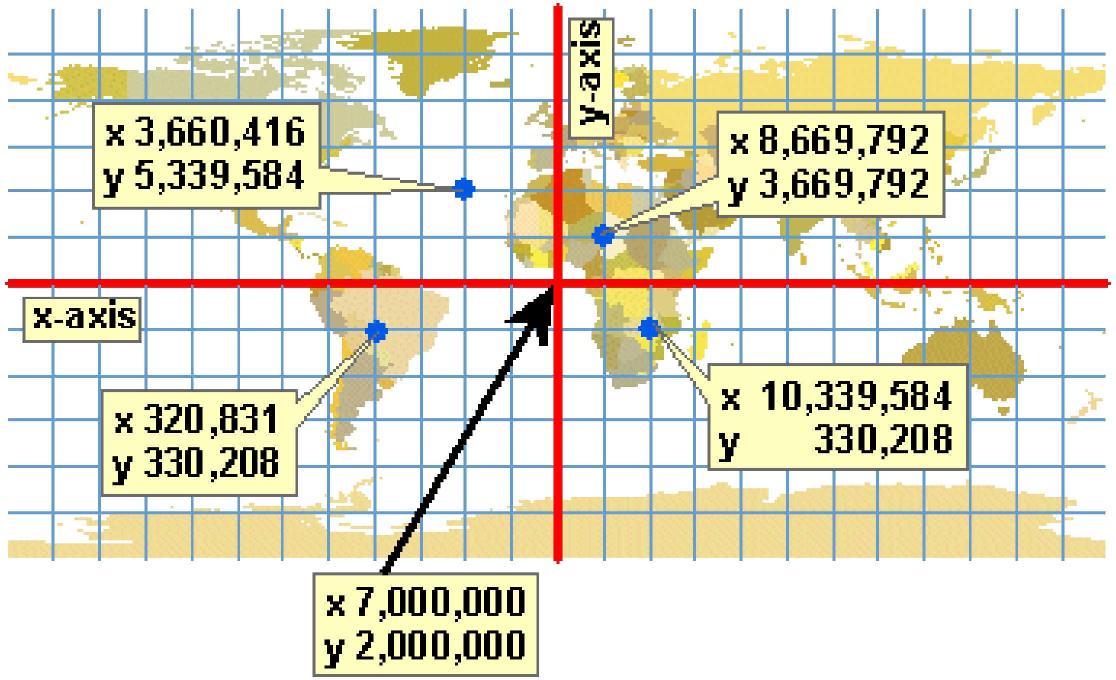
Coordinate reference systems (CRS)

X: longitude, Y: latitude



Geographic coordinates are defined as angles measured from the center of a spheroid/ellipsoid

X: Easting, Y: Northing

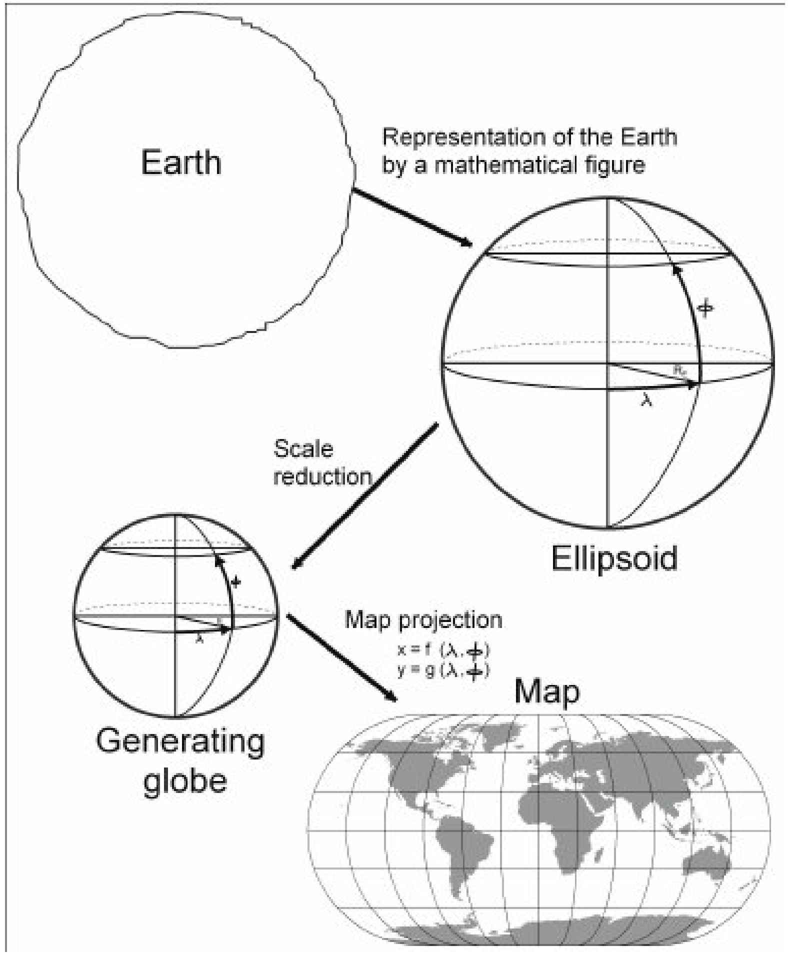


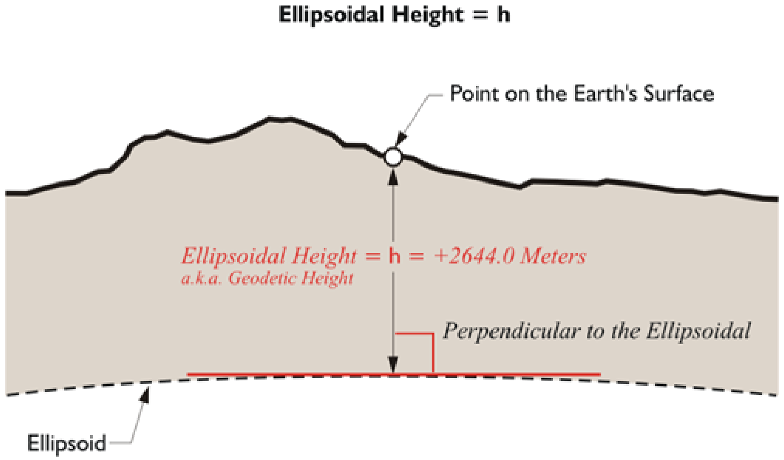
Projected coordinates are defined on Cartesian axes

Datums

A **datum** is the information that fixes a coordinate system to some reference object (the Earth/Geoid)

- Horizontal datums:
    1. Ellipsoid model of earth with geodetic datum (**geographic coordinates**)
    2. Map projection (**projected coordinates**)
    (The second step might be omitted)
- Vertical datums (fixing height). For example **ellipsoidal height**.





Geodetic datums for geographic coordinates

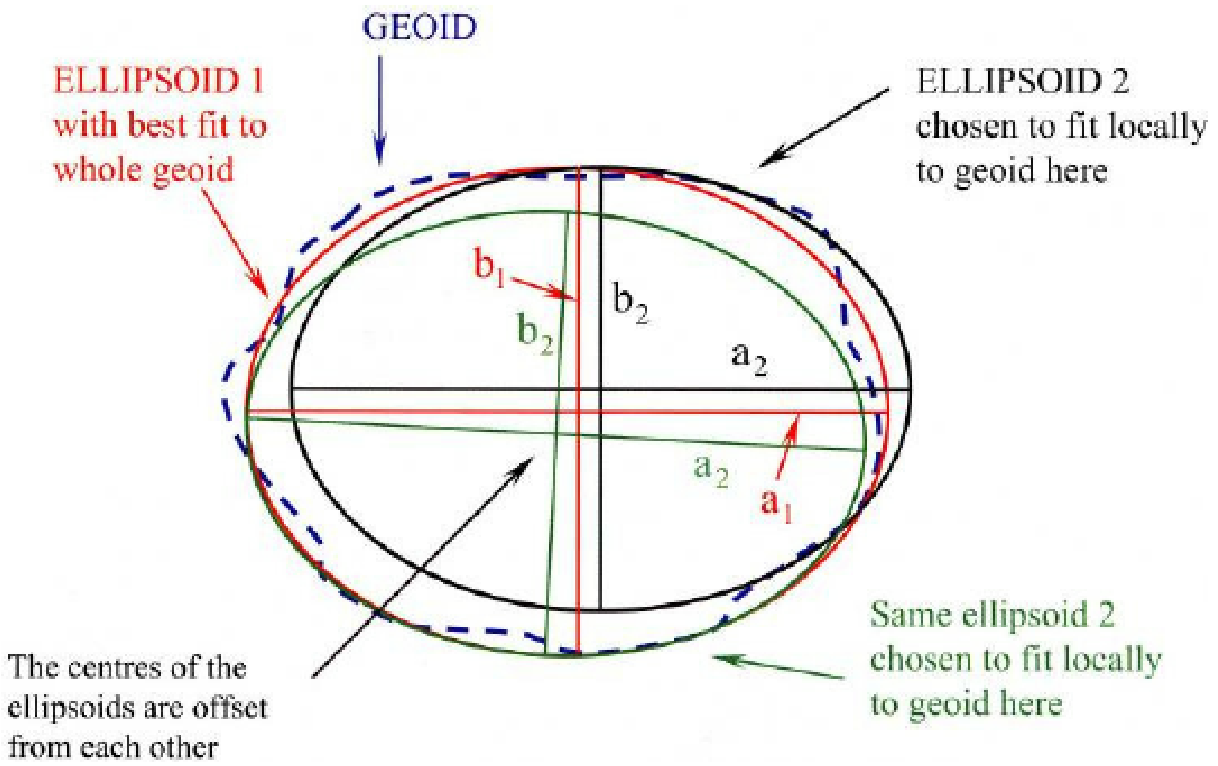
each datum needs measurements - fixing the ellisoid to adjust the position (realization)

most important datum/reference system WGS84 when the measurements established the system in 1984

Horizonal (geodetic) datum consists of:

- *Reference Ellipsoid* (defined by major and minor axis lengths)…
- … fixed relative to the earth via a *standard position* (fundamental point)
- … some *standard orientation* (of minor axis, aligned with poles)
- … *and the location of prime meridian (*0 degree, e.g. Greenwich)

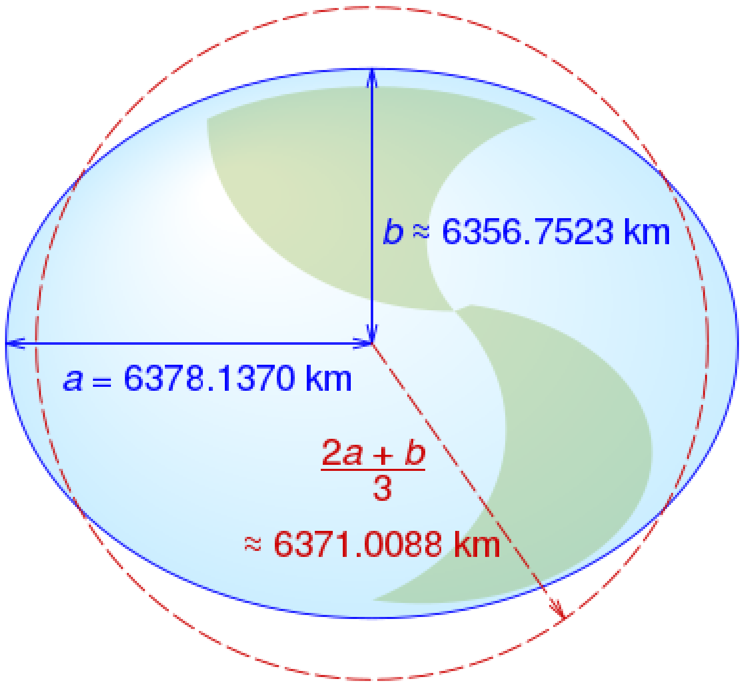
Different "realizations" of datums in different years (e.g. *WGS84* = World Geodetic System of 1984)



Reference Ellipsoids: examples

Name	*Equatorial (Major) Axis in Meters*	*Flattening (1/f)*	*Region*
Airy 1830	6377563	299.325	Great Britain
Bessel 1841	6377397.2	299.153	Central Europe
Everest 1830	6377276.3	300.80	Indian subcontinent
Clarke's 1866	6378206.4	294.98	North America
Clarke's 1880	6378249.2	293.47	Africa; France
Krasovsky 1940	6378245	298.2	Former Soviet Union
World Geodetic System 1972	6378135	298.26	NASA, U.S. military
GRS 1980/ WGS 84[b]	6378137	298.257	GPS, new systems

WGS 84 ellipsoid
(used by GPS)



Map projections

How to get from an ellipsoid to the plane? Not without information loss!

Defined by:

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

Extent	Distortion Property	Projection
World	Equal-area	Mollweide
		Hammer (or Hammer-Aitoff)
		Boggs Eumorphic
		Sinusoidal
		Eckert IV
		Wagner IV (or Putnins P2')
		Wagner VII (or Hammer-Wagner)
		McBryde-Thomas flat-polar quartic
		Eckert VI
		Goode homolosine
		McBryde S3
	Compromise	Natural Earth
		Winkel Tripel
		Robinson
		Wagner V
		Patterson (cylindrical)
		Plate Carrée (cylindrical)[1]
		Miller cylindrical I
	Equidistant	Azimuthal equidistant[2]
		Two-point equidistant
Hemisphere	Equal-area	Lambert azimuthal equal-area
	Equidistant	Azimuthal equidistant[2]
Continent, ocean, or smaller area	Equal-area	Lambert azimuthal equal-area
		Albers conic
		Cylindrical equal-area
		Transverse cylindrical equal-area
	Conformal	Stereographic
		Lambert conformal conic
		Mercator
		Transverse Mercator
	Equidistant	Azimuthal equidistant[2]
		Plate Carrée[1]
		Equidistant conic

Notes: [1]The Plate Carrée projection is suggested twice, for world maps with compromise distortion and for continents, oceans or smaller areas with equidistant distortion property.
[2]The azimuthal equidistant projection is suggested for all three extents

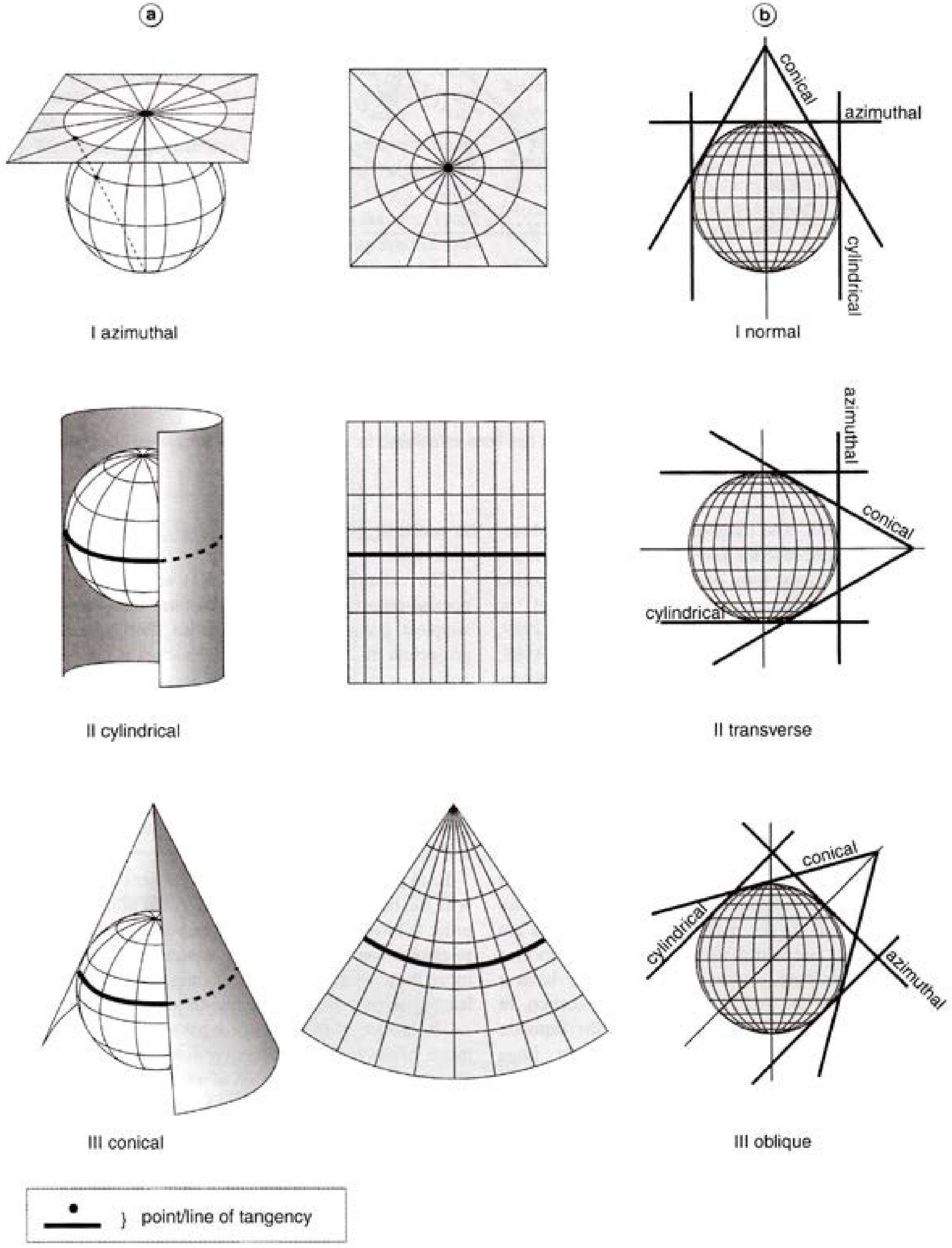
Map projections

Class:

- Cylindrical
- Azimuthal
- Conic

Aspects:

- Oblique
- Transverse
- Normal



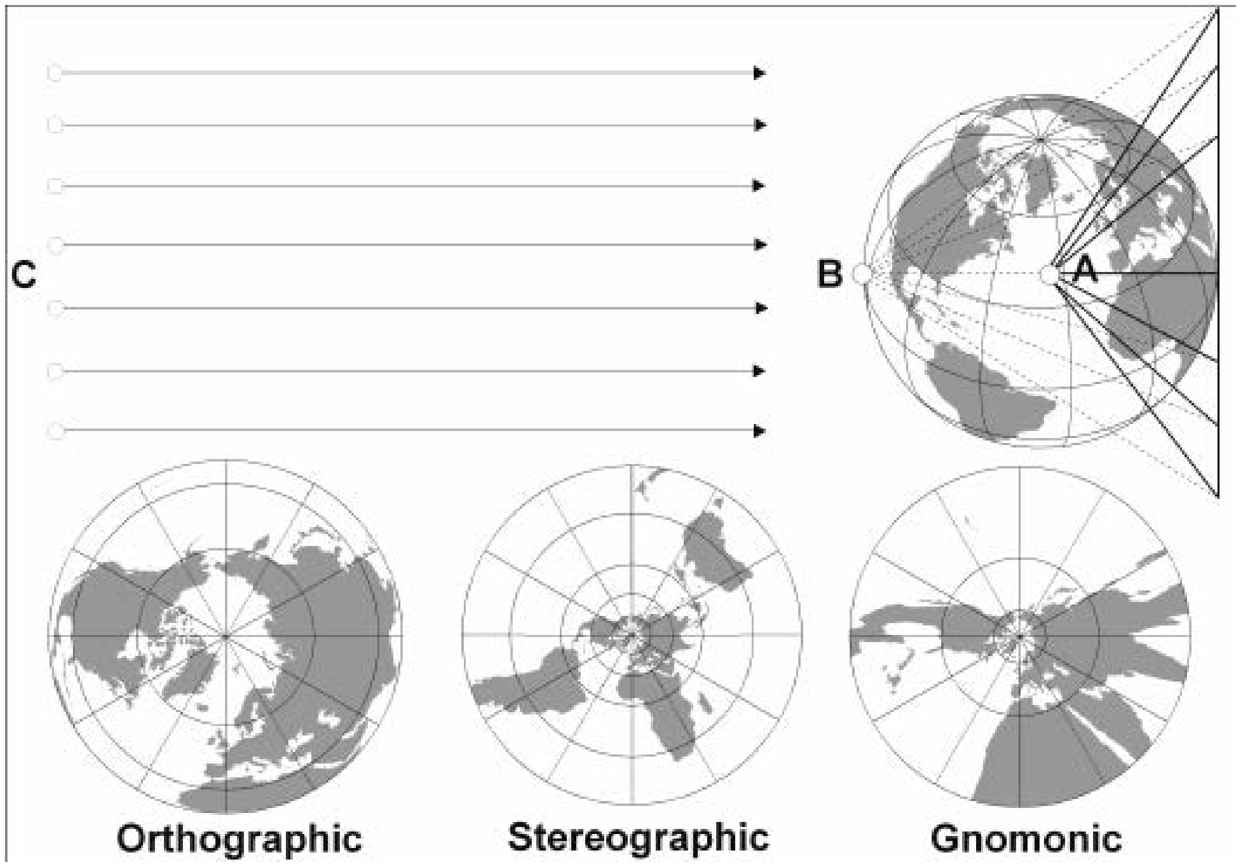
Map projections: information loss

- In a ***conformal*** (***orthomorphic***) map projection the angles between lines in the map are identical 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).

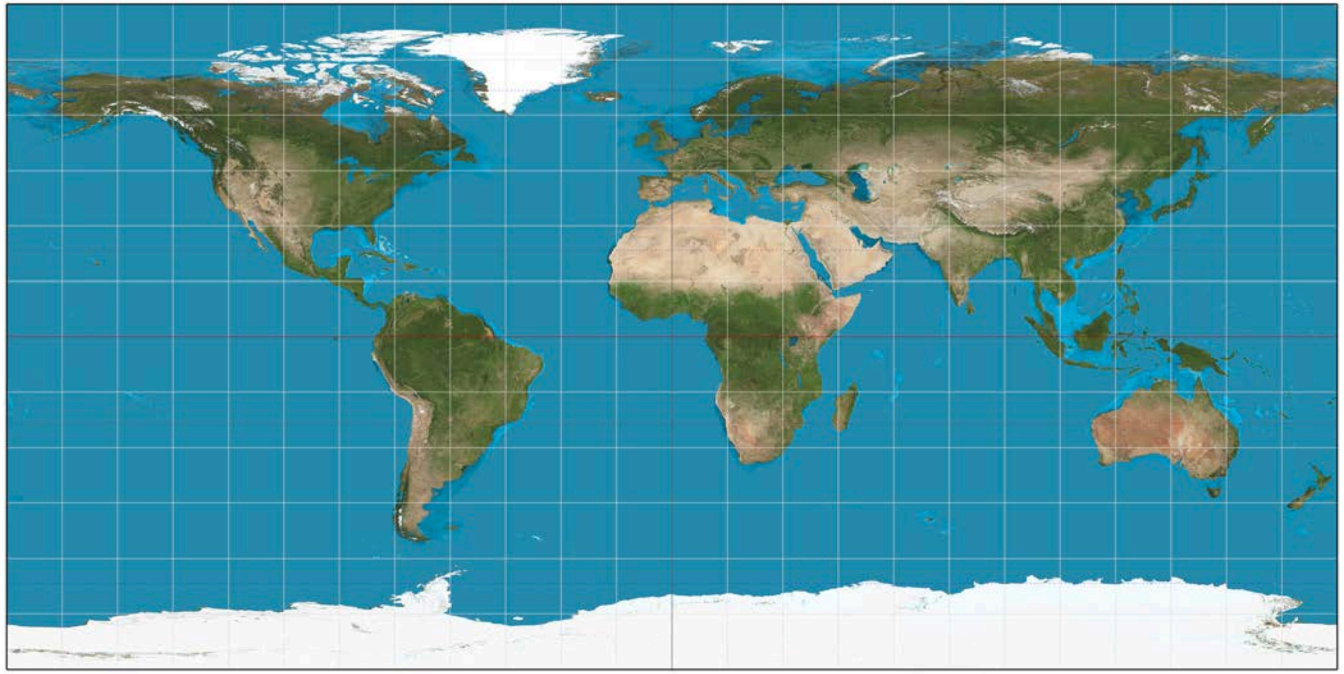
Map projections: mathematical projections

How to get from an ellipsoid to the plane? Not without information loss!

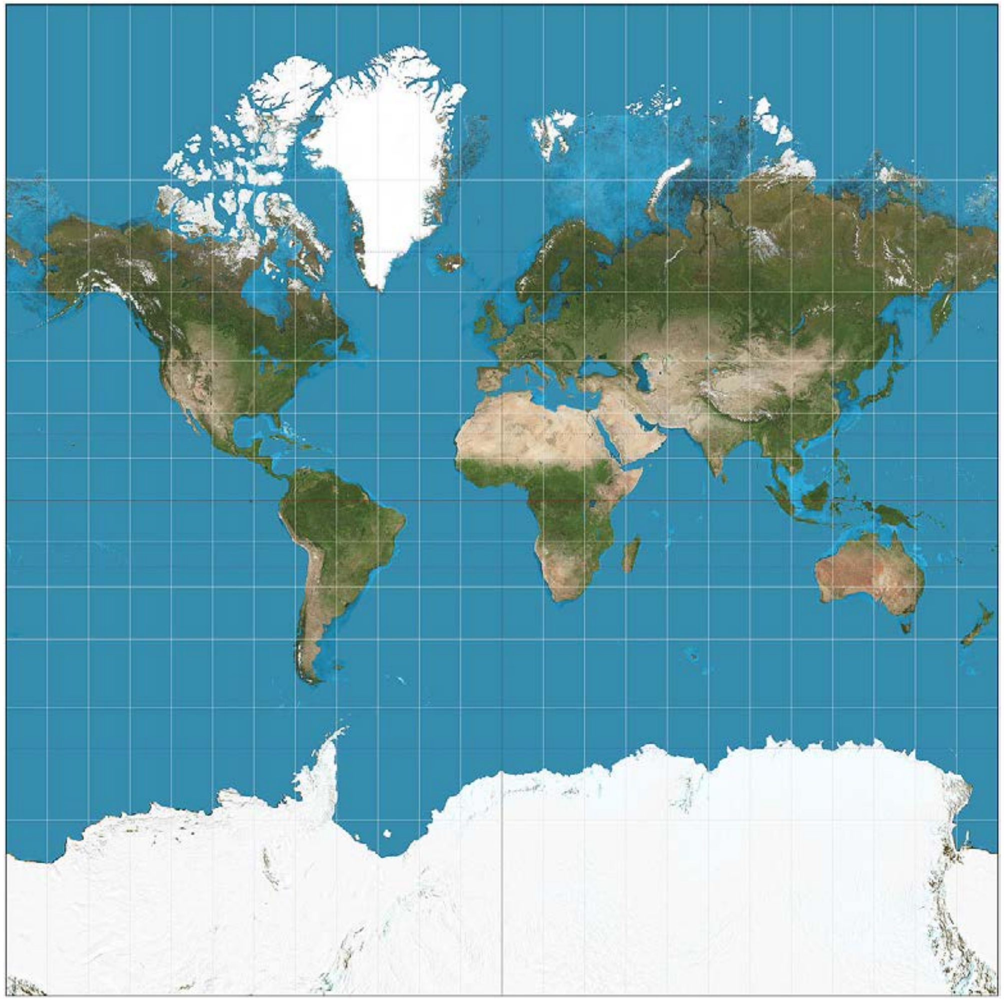
- A) Gnomonic
  (from center)
- B) Stereographic
  (from opposite side)
- C) Orthographic
  (parallel projection)



Map projections: examples

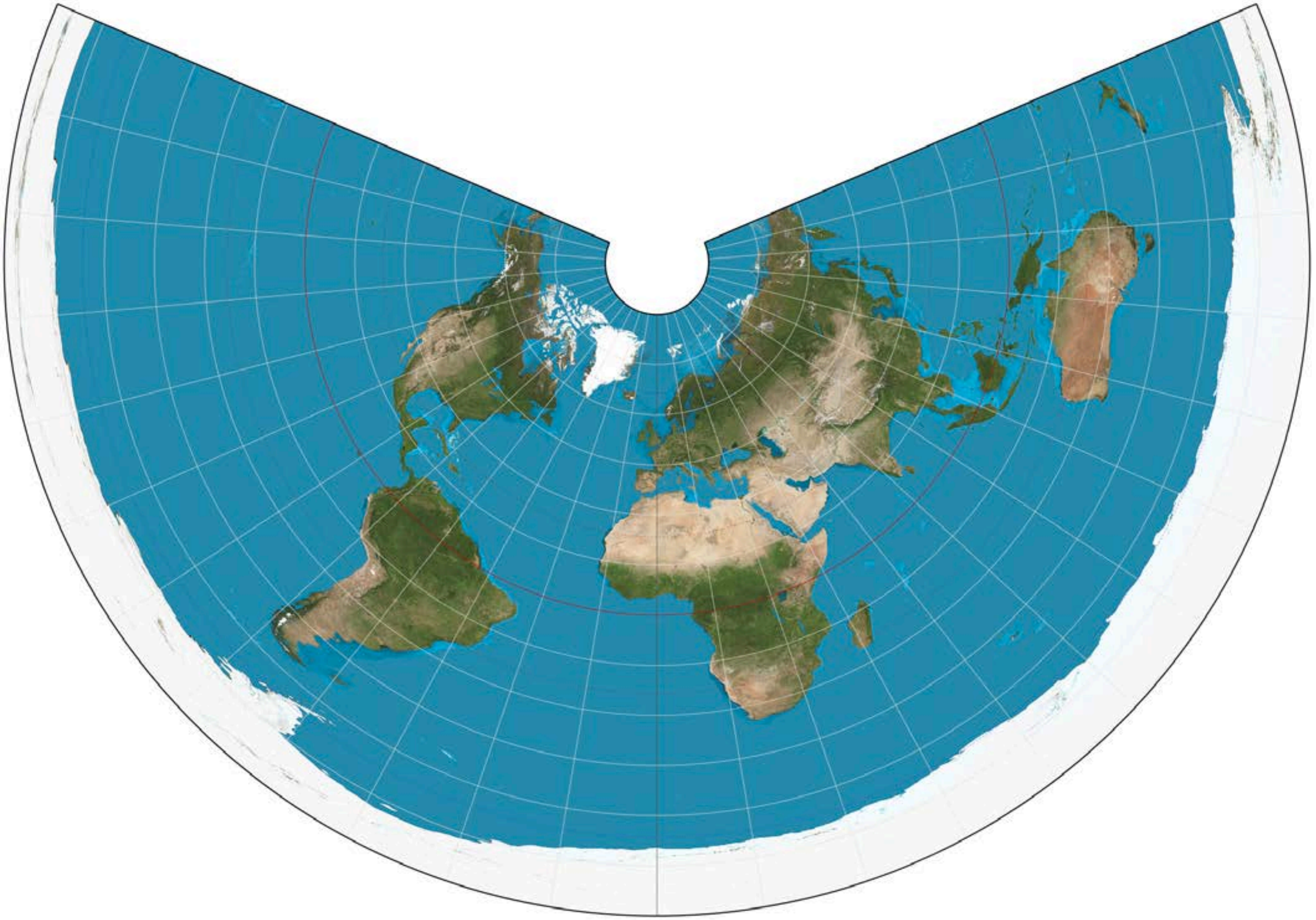


Cylindrical equidistant projection
(preserve distances along meridians)

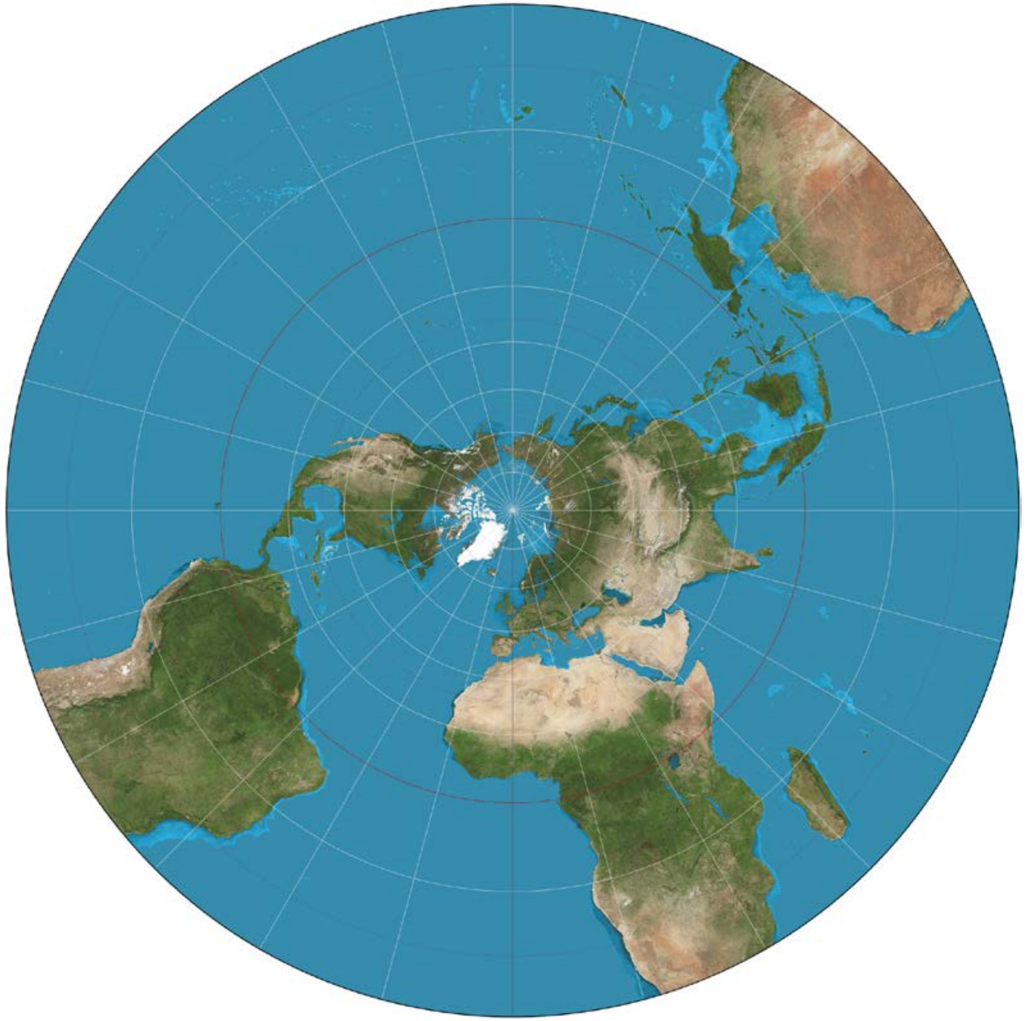


Mercator (cylindrical conformal) projection
(preserves angles)

Map projections: examples



Conic equidistant projection
(preserves distances along meridians)



Stereographic (conformal) projection
(preserves angles)

For the Netherlands: Amersfoort / RD New

- “Rijksdriehoekscoördinaten”
- Defined as WKT (well known text):

```
PROJCS["Amersfoort / RD New",
    GEOGCS["Amersfoort",
        DATUM["Amersfoort",
            SPHEROID["Bessel 1841",6377397.155,299.1528128,
                AUTHORITY["EPSG","7004"]],
            AUTHORITY["EPSG","6289"]],
        PRIMEM["Greenwich",0,
            AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.01745329251994328,
            AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","4289"]],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    PROJECTION["Oblique_Stereographic"],
    PARAMETER["latitude_of_origin",52.15616055555555],
    PARAMETER["central_meridian",5.38763888888889],
    PARAMETER["scale_factor",0.9999079],
    PARAMETER["false_easting",155000],
    PARAMETER["false_northing",463000],
    AUTHORITY["EPSG","28992"],
    AXIS["X",EAST],
    AXIS["Y",NORTH]]
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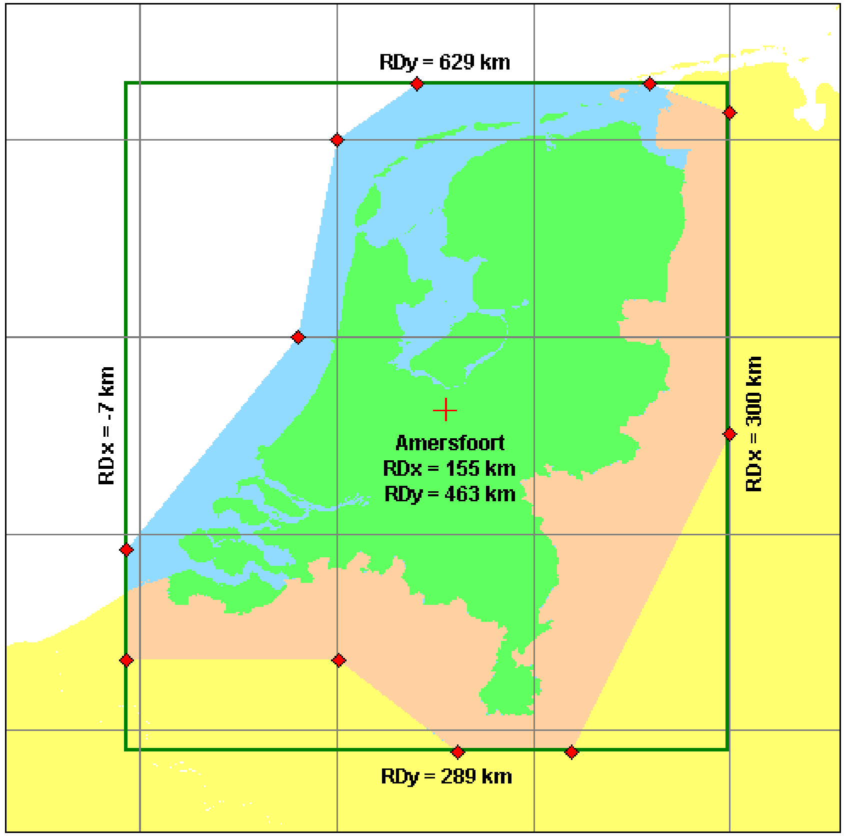
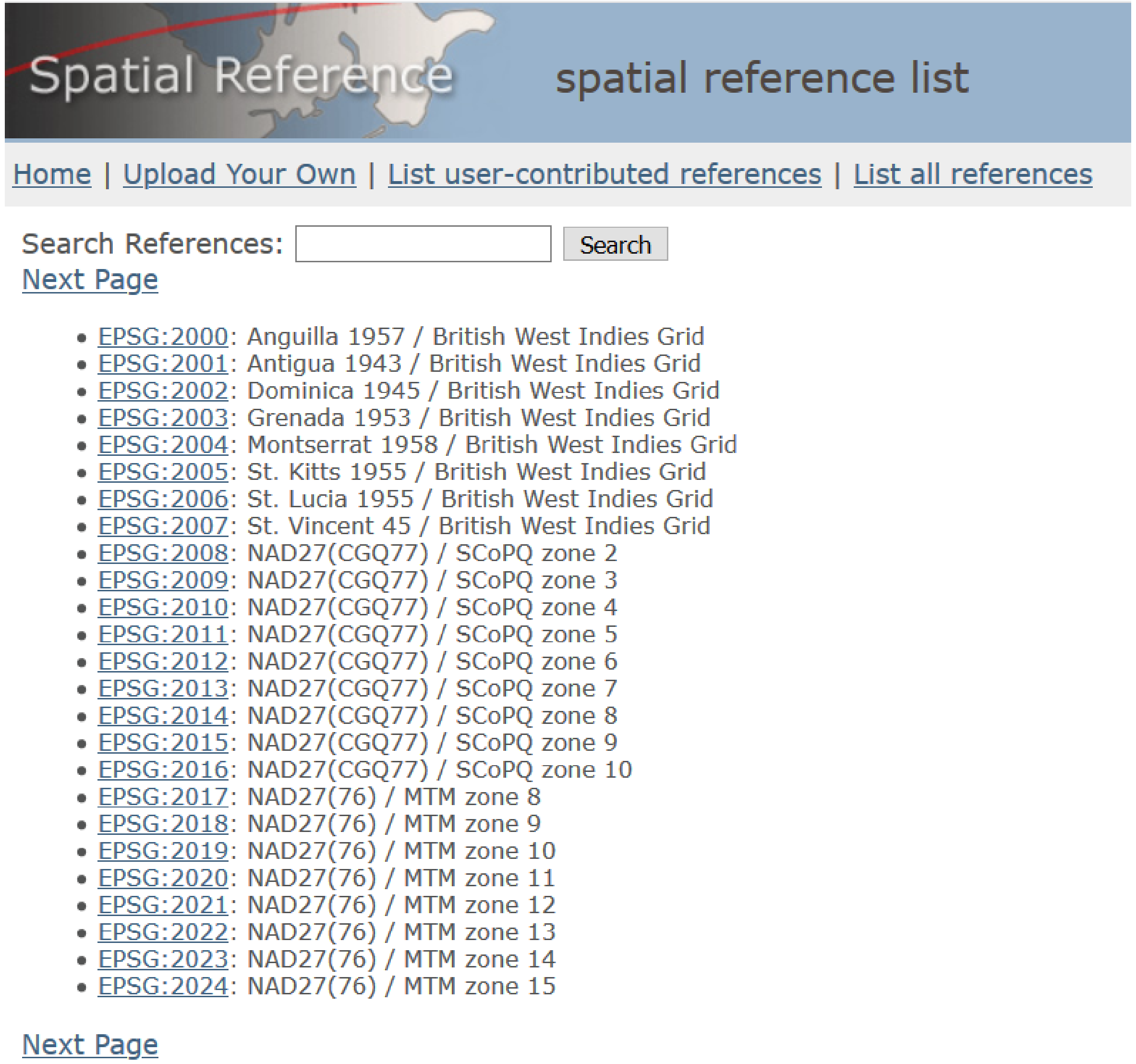


EPSG standardization of CRS

- CRS are standardized by “European Petroleum Survey Group (EPSG)”
- Provided as unique URI on https://spatialreference.org

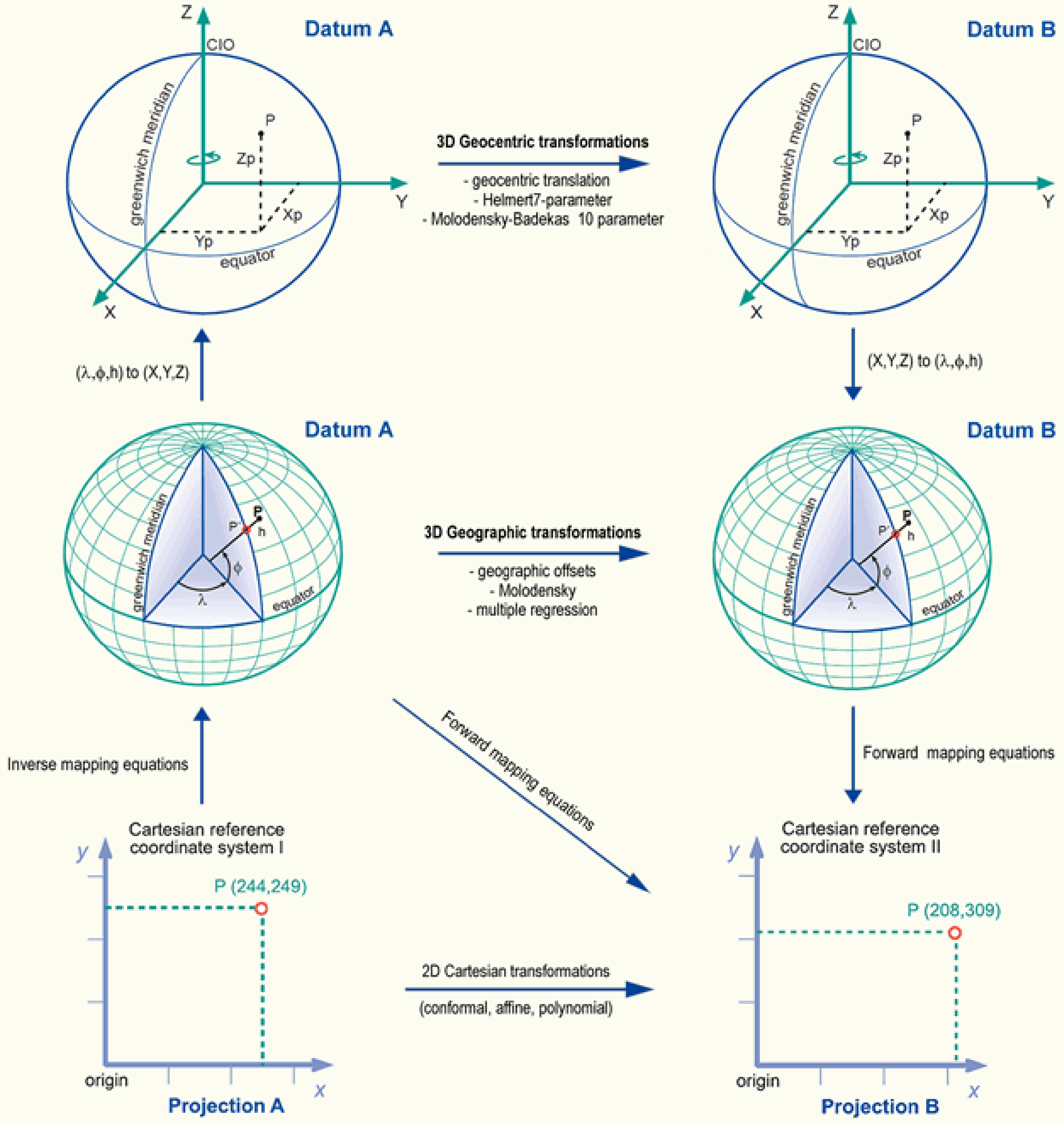


CRS Transformations

Are needed to homogenize geodata.

Three principal approaches:

1. Geocentric transformations (via geocentric cartesian coordinates)
2. Geographic transformations (via coordinate offsets)
3. 2D plane (affine, polynomial) transformations

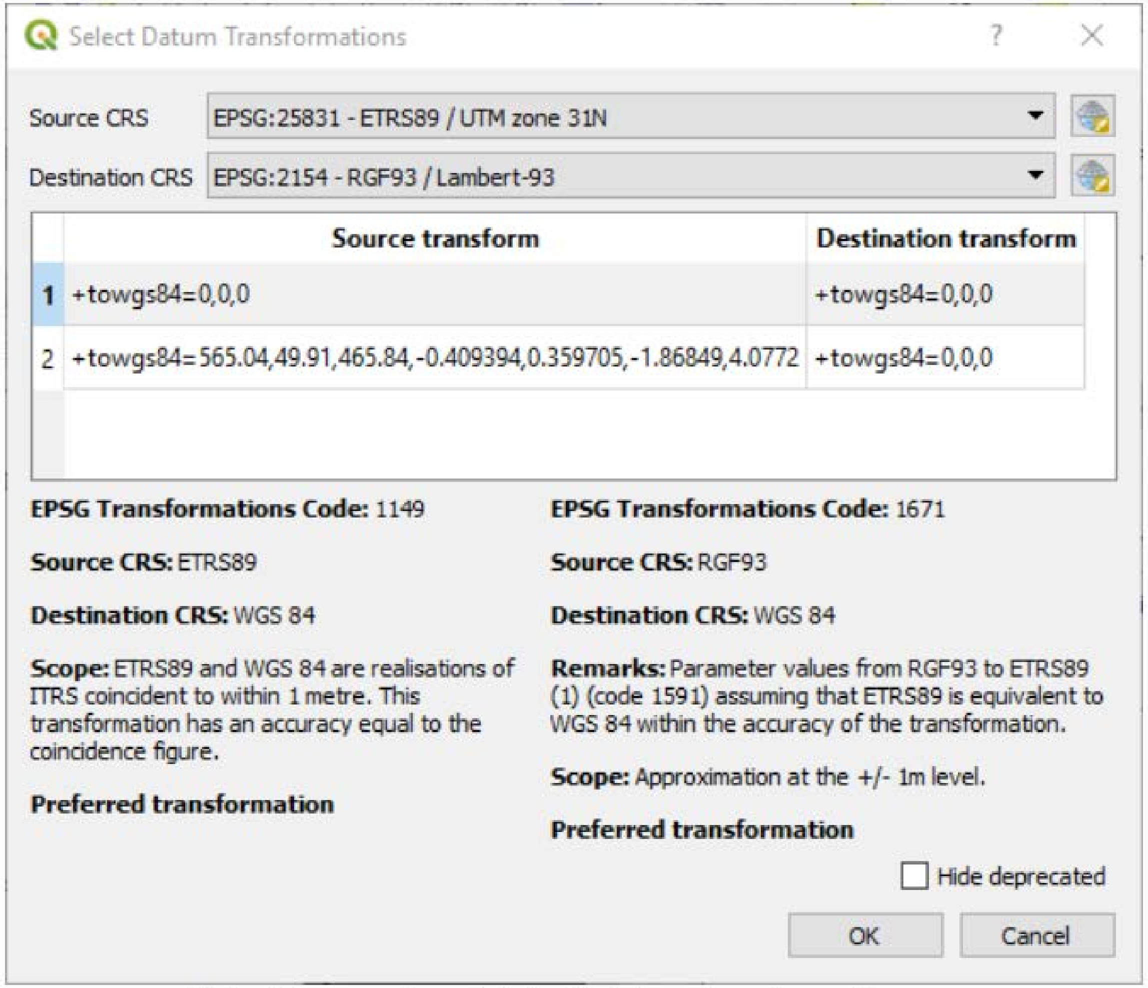


CRS Transformations

To compute transformations, origin and destination CRS must be known. In QGIS, you can:

- Use default (on-the-fly) transformations (e.g. all data is projected to the main "project CRS")
- choose explicit datum transformations (right)

Always first homogenize CRS of data sources!! You can re-project data by saving a layer under a chosen CRS.



Selecting a preferred default datum transformation

https://docs.qgis.org/testing/en/docs/training_manual/vector_analysis/reproject_transform.html

Questions?
(Q&A session)

References

- Chapter (you need to read this!)
  “Reference Systems for Measurement"
  in Chrisman, N. (2002) “Exploring geographic information systems”, Wiley
- Iliffe, J. and Lott, R. (2000): Datums and Map Projections (second edition). Whittles Publishing