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4 Coordinate Reference Systems and Projections

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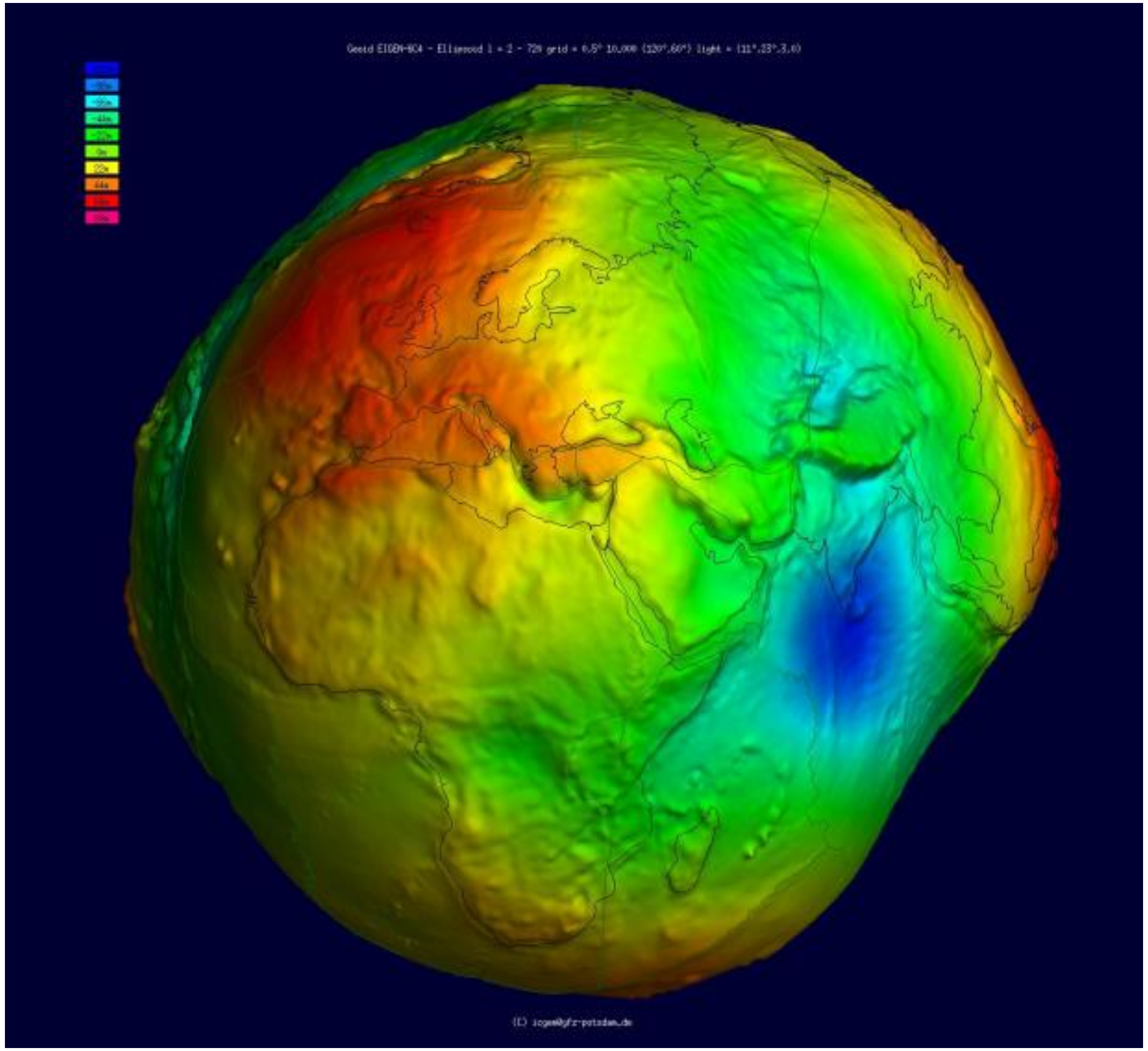
EARTH OBSERVATION RESEARCH

Coordinate Reference Systems

Geoid

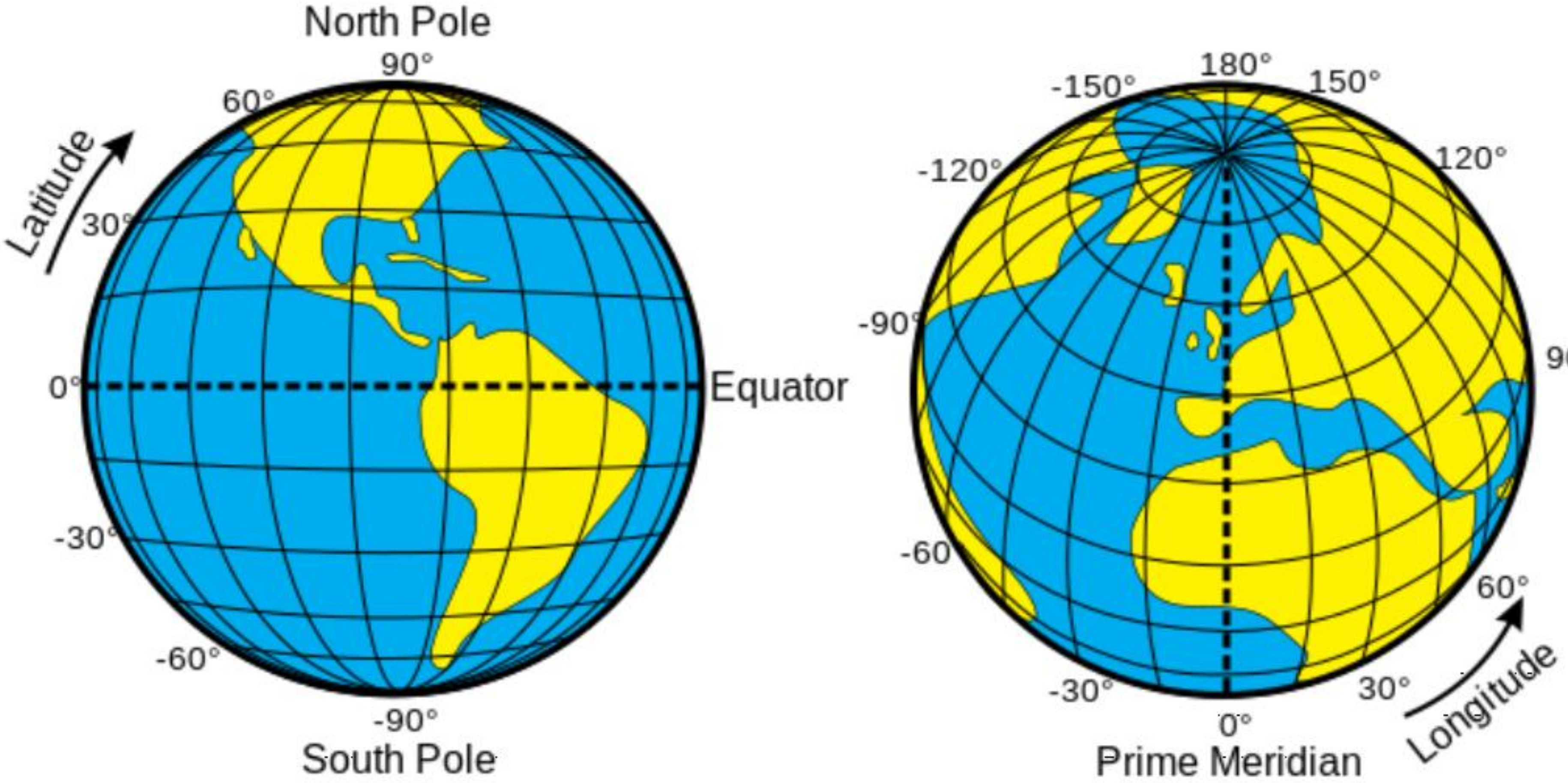
The “blue marble” – or is marble really the right term?
NASA, 2000

Geoid



The Geoid (scale factor: 1000).
Wikimedia Commons, 2022

Geographic Coordinate System



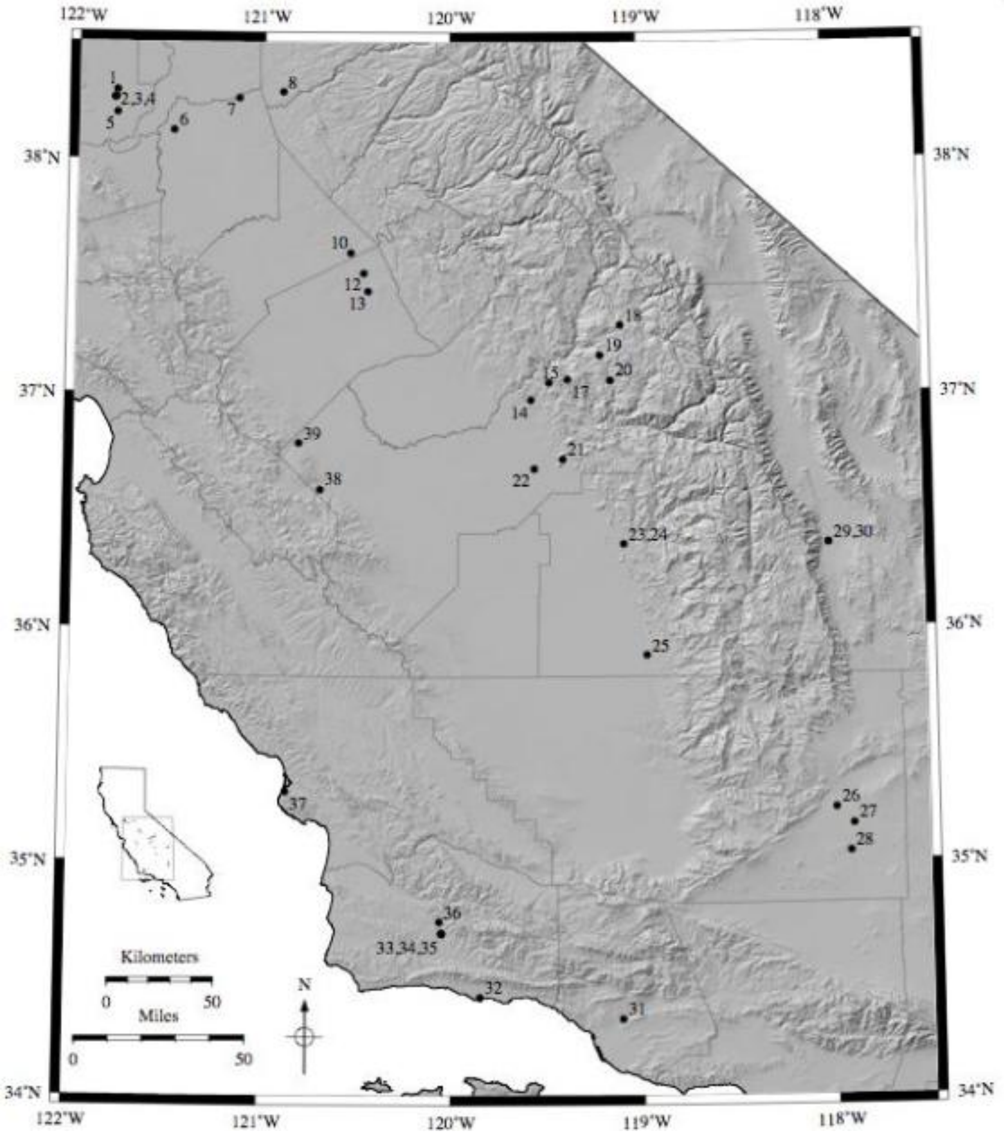
The Earth's Geographic Coordinate System: unlike cartesian systems it is not planar, but spherical and uses angles (latitudes and longitudes) to describe locations. Wikimedia Commons, 2022

Geographic Coordinate System

Localization on Earth:

- Geoid: geometric shape of the Earth approximated as a rotating sphere (ellipsoid)
- Geographic Coordinate System:
  - Latitude: angle between *perpendicular* of rotating sphere and *equatorial plane* at point on sphere
  - Longitude: angle between *prime meridian* and a plane through *North and South pole* at point on sphere
- Equatorial plane: simply derivable from the axis of rotation (natural)
- Prime Meridian: artificially defined, Eastern and Western hemisphere

Geographic Coordinate System

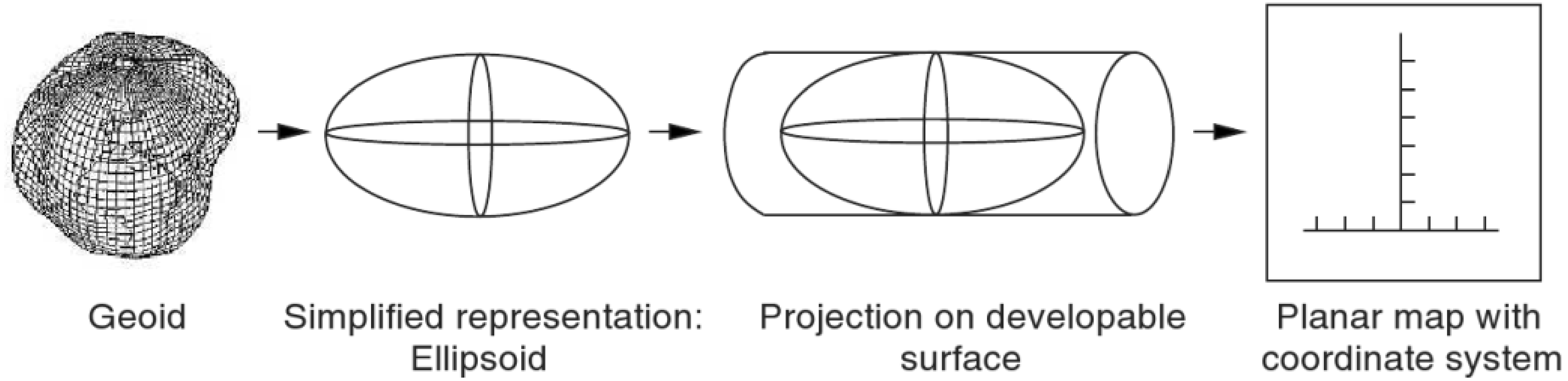


The Geographic Coordinate System is using 360 longitudes and 180 latitudes and uses the following systems:

- DD: Decimal Degrees (29.1000°, -113.3000°)
- DM: Degrees Decimal Minutes (39°33.0’, -125°31.0)
- DMS: Degrees Minutes Seconds (39°23’05’’N, 113°27’01’’W)

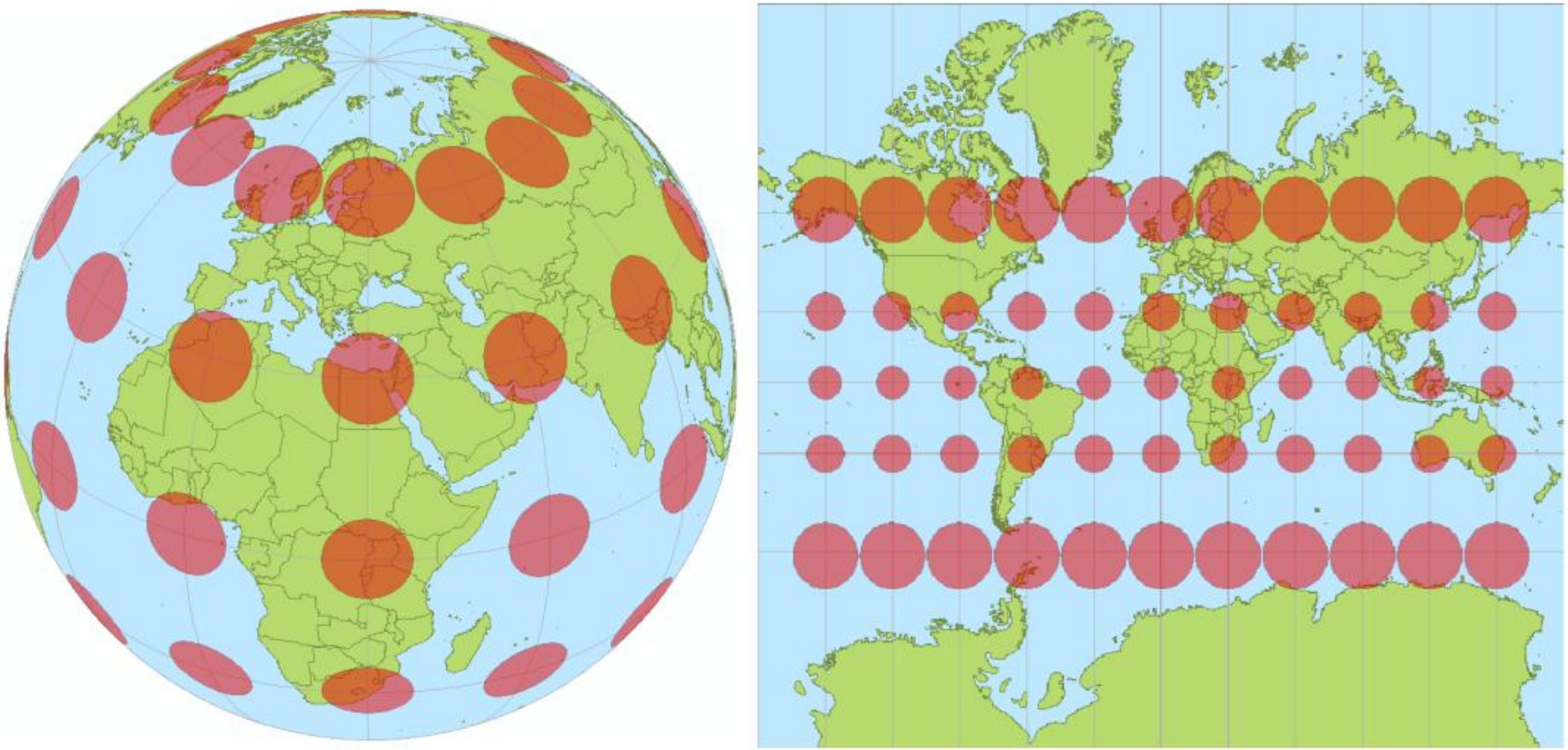
What is a projection?

Projecting



Projecting a spherical surface onto a plane. (Neteler and Mitasova 2008)

Projecting - Distortions



Distortions visualized for the often-used Mercator projection: Direction and shapes are correct, but area and distance are distorted.
(Wikimedia Commons, 2022)

Projecting

Projecting Earth’s spherical surface onto a plane:

- Projection: Transfer of the 3D-shape of the Earth’s surface onto a 2D-plane (e.g., a map) ⍰ non-trivial mathematical problem
- Projected coordinate system: Points to locations on a plane
- Geometry: There are four fundamental geometric properties to any geometric feature on a sphere: (i) area, (ii) distance, (iii) direction and (iv) shape
- Distortions: only two of these four can be preserved by a single projection ⍰ mathematical constraint

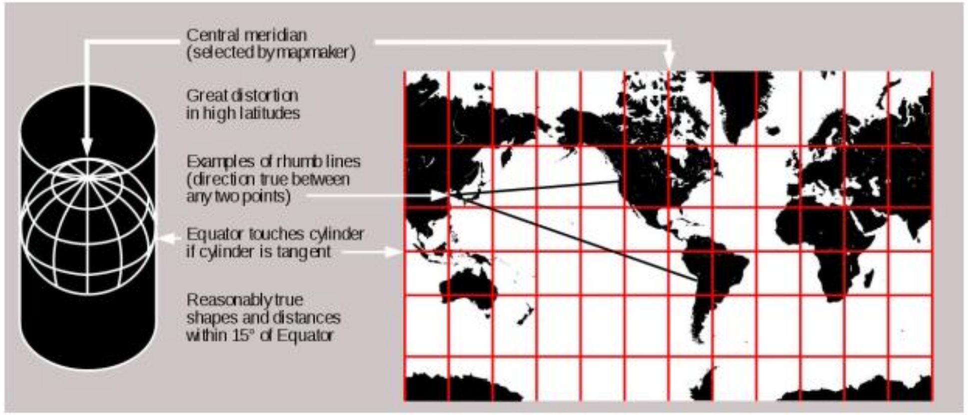
Projecting – why?

- Projections allow you to work with spherical data on a cartesian-like grid with dimensions and units easy to interpret
- Earth observation and other spatial data are delivered projected, and you need to be able to deal with their projection
- If you use data from different sources, you need to be able to reproject them to a uniform projection
- Thus, you need to be able to decide which projection to use for your project
- You might need to project unprojected (geographical, spherical) data to jointly analyze them with projected data

Projecting – What kind of projections exist?

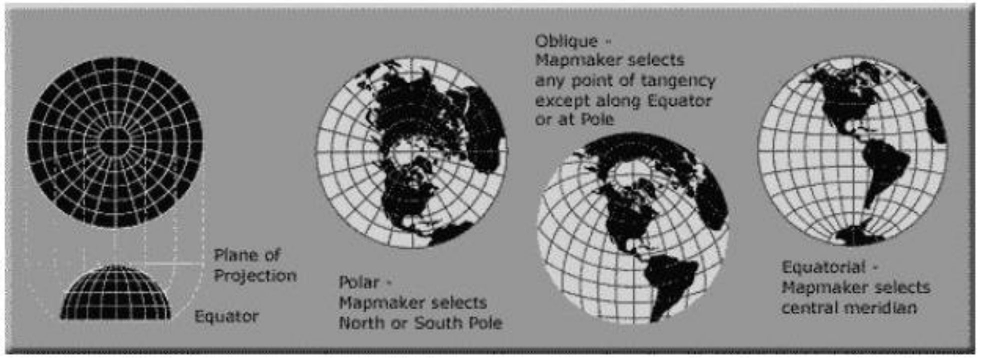
- **Conformal**: map projections preserving angles locally and thereby shape
- **Equal-Area**: map projections preserving area
- **Equidistant**: map projections preserving distance
- **True direction**: map projections preserving direction

Projecting – Different ways



(USGS Projection Map, 2023)

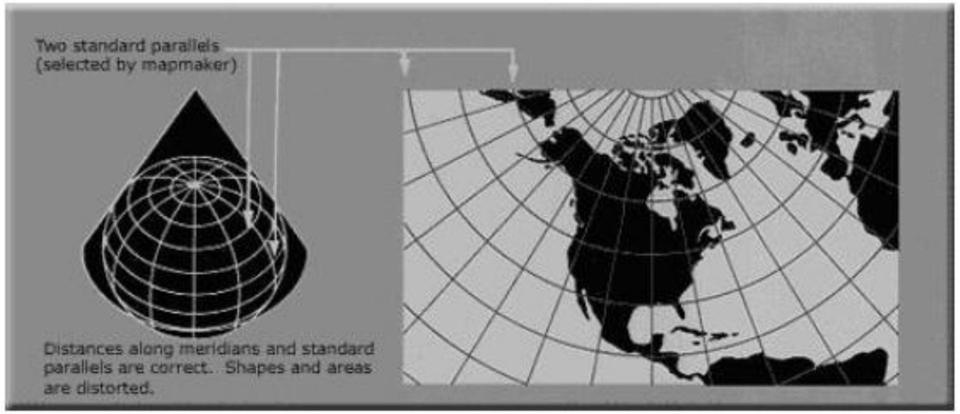
Cylindrical



(USGS Projection Map, 1993)

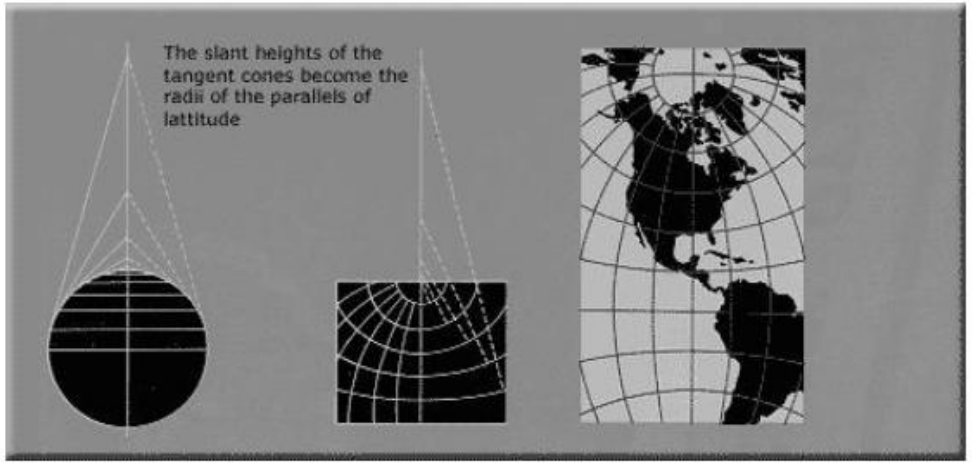
Azimuthal (planar)

Projecting – Different ways



(USGS Projection Map, 2023)

Conic



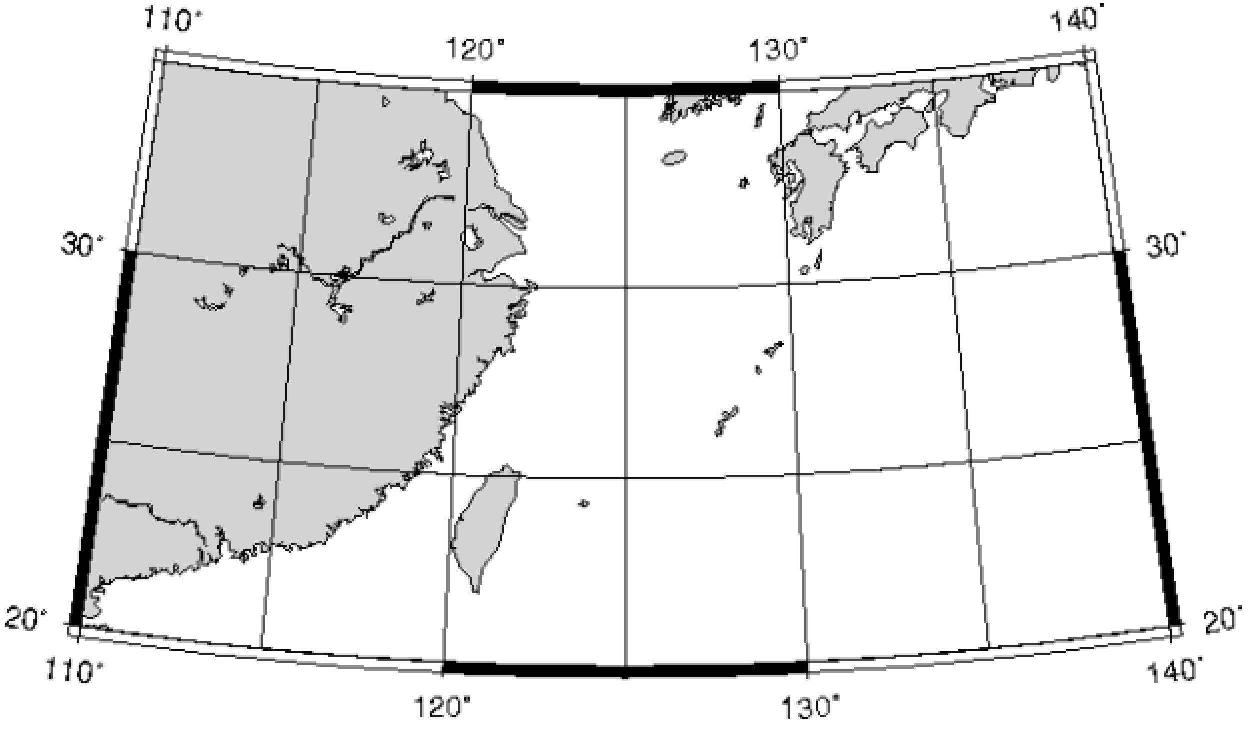
(USGS Projection Map, 1993)

Polyconic

Conic Projections

Albers Conic Equal Area Projection

- Used to map regions of large east-west extent
- More closely spaced at the north edge of the map
- Projection is equal area

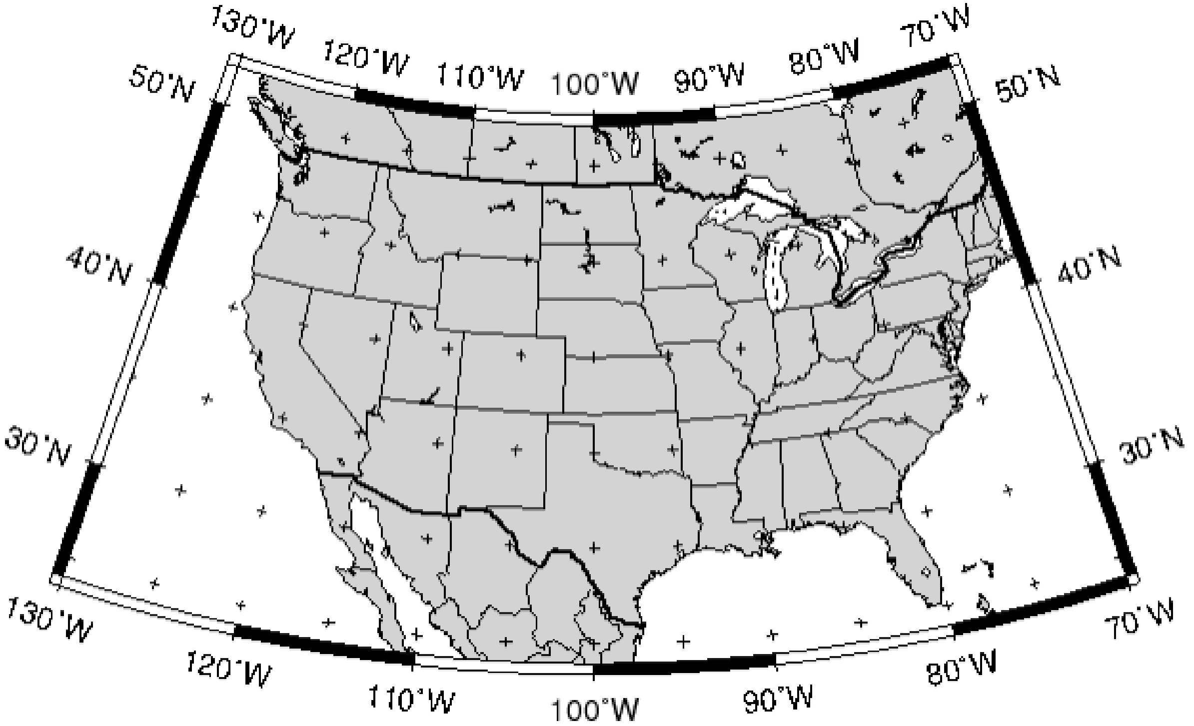


Albers Conic Equal Area (created by GMT)

Conic Projections

Lambert Conic Conformal Projection

- Similar to the Albers projection to map regions of large east-west content
- Unlike the Albers projection, Lambert's conformal projection is not equal-area

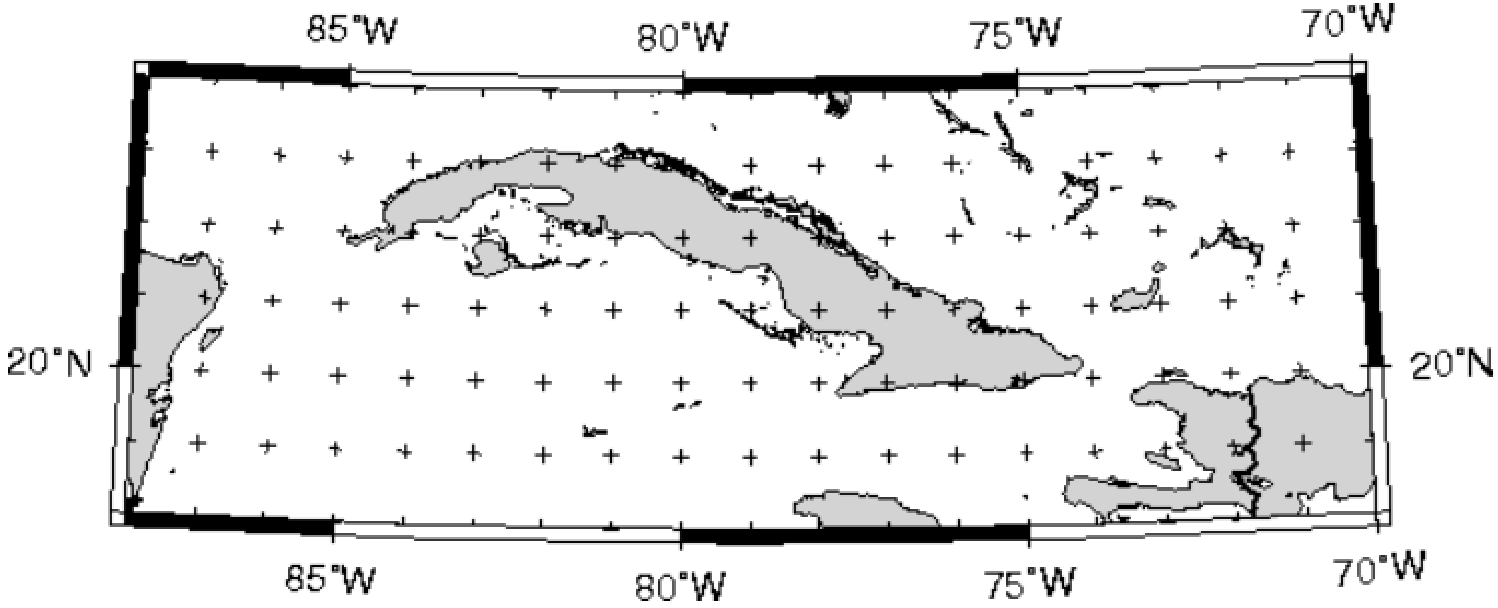


Lambert Conic Conformal (created by GMT)

Conic Projections

Equidistant Conic Projection

- Neither conformal or equal-area, but serves as a compromise between them



Equidistant Conic (created by GMT)

Azimuthal Projections

Lambert Azimuthal Equal Area Projection

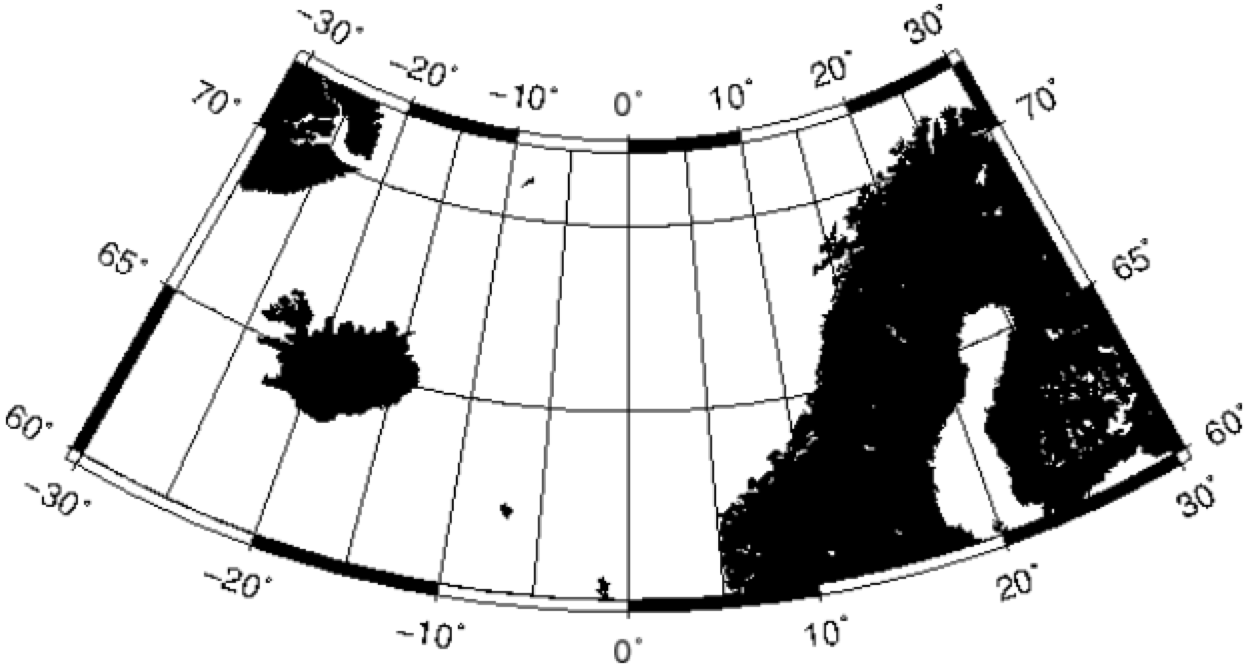
- Developed in 1772 by Lambert
- Used for mapping large regions (e.g., continents)
- It is an azimuthal, equal-area projection but not perspective

Lambert Azimuthal Equal Area (created by GMT)

Azimuthal Projections

Polar Stereographic Conformal Projection

- Conformal and azimuthal
- Dates back to the Greeks
- Main use for mapping polar regions



Polar Stereographic Conformal (created by GMT)

Azimuthal Projections

Orthographic Projection

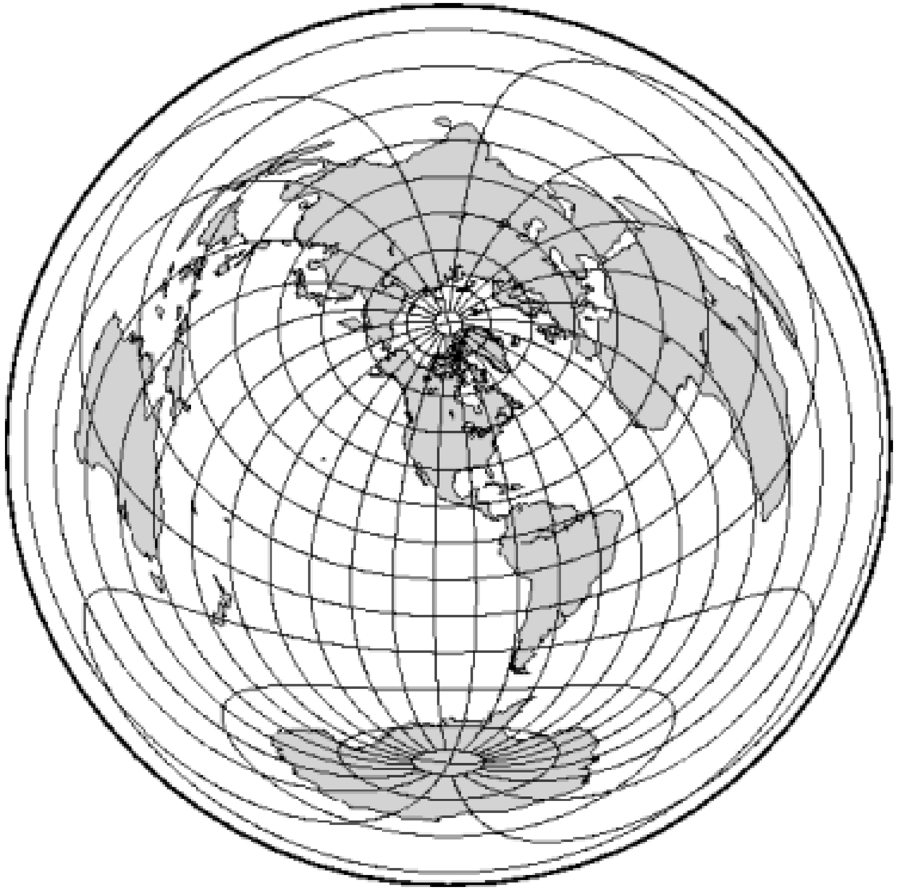
- Perspective from an infinite distance
- Used for appearance of the earth from space
- Much distortion is introduced

Orthographic (created by GMT)

Azimuthal Projections

Equidistant Azimuthal Projection

- Direction from the center is true
- Several centuries old

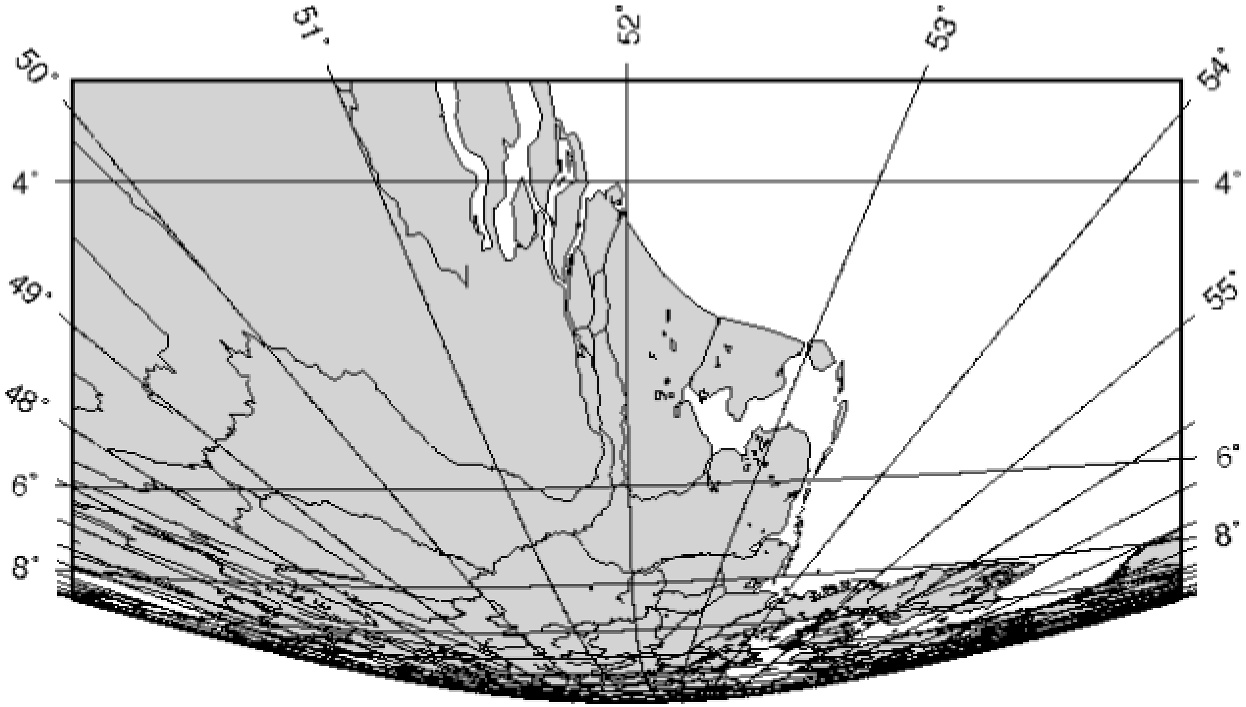


Equidistant Azimuthal (created by GMT)

Azimuthal Projections

Perspective Projection

- Used for a 3D appearance on a 2D plane

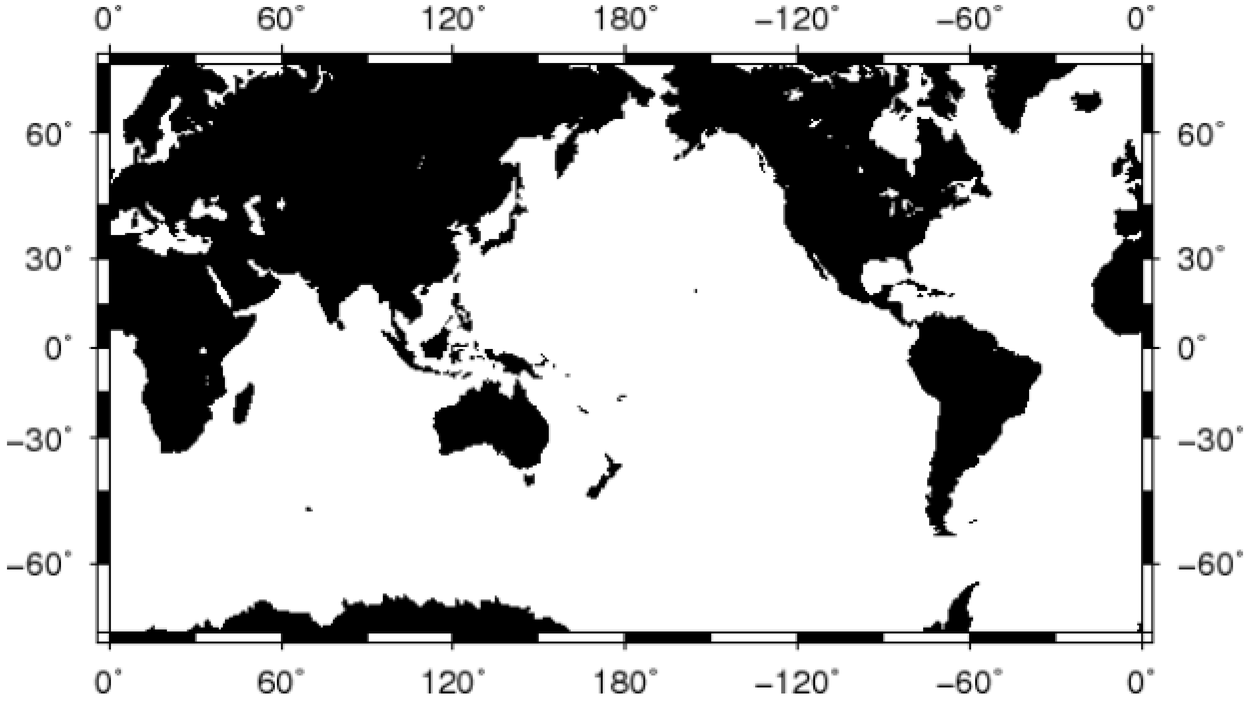


Perspective (created by GMT)

Cylindrical Projections

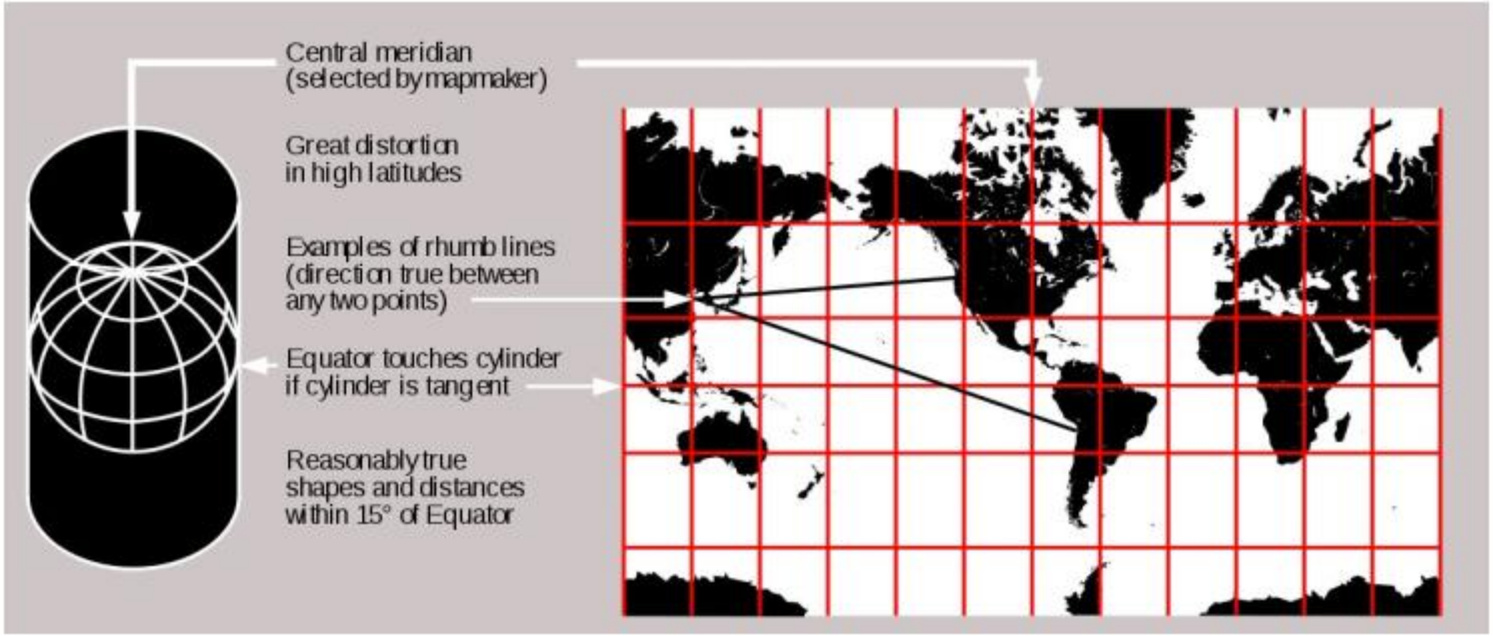
Mercator Projection

- Probably most famous
- Originated from G. Cremer (Flemish cartographer, 1569)
- Cylindrical and conformal, no distortion along equator
- Distortion towards poles larger (e.g., Greenland larger than S-America



Mercator (created by GMT)

Cylindrical Projections

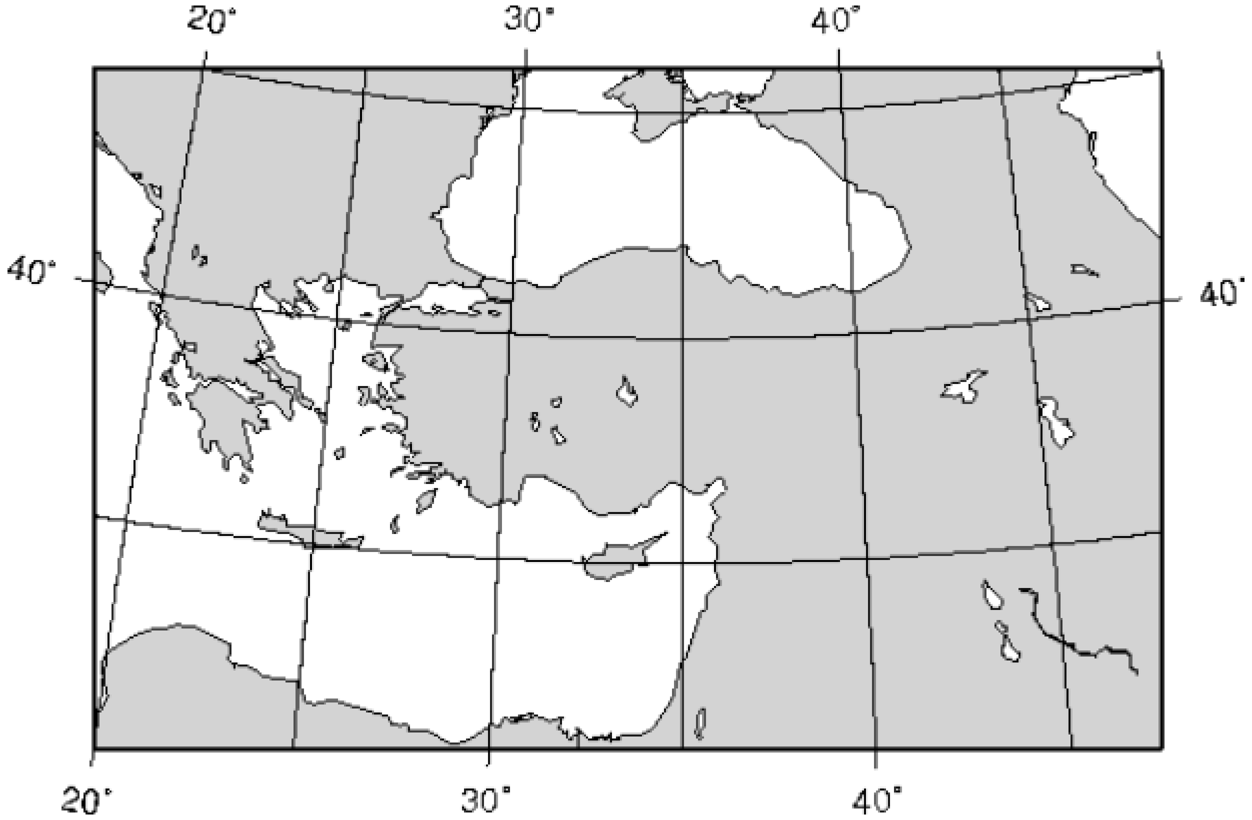


Mercator (USGS)

Cylindrical Projections

Transverse Mercator Projection

- Lambert 1772
- Distortion increases away from the central meridian

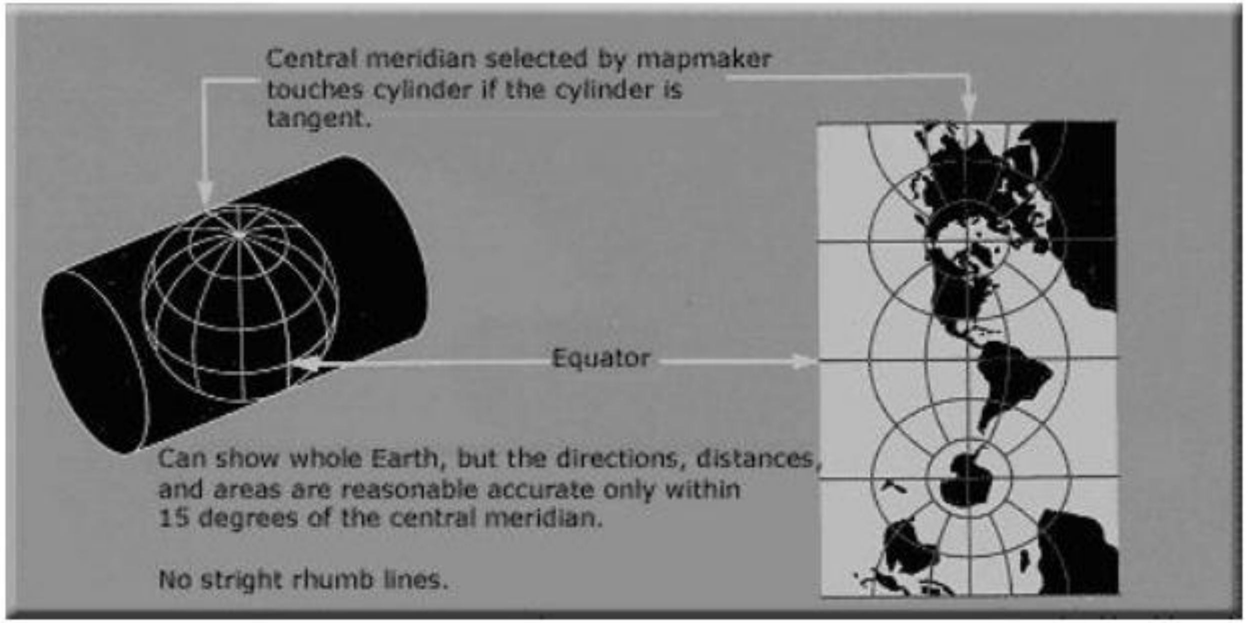


Transverse Mercator (created by GMT)

Cylindrical Projections

Transverse Mercator Projection

- Lambert 1772
- Distortion increases away from the central meridian

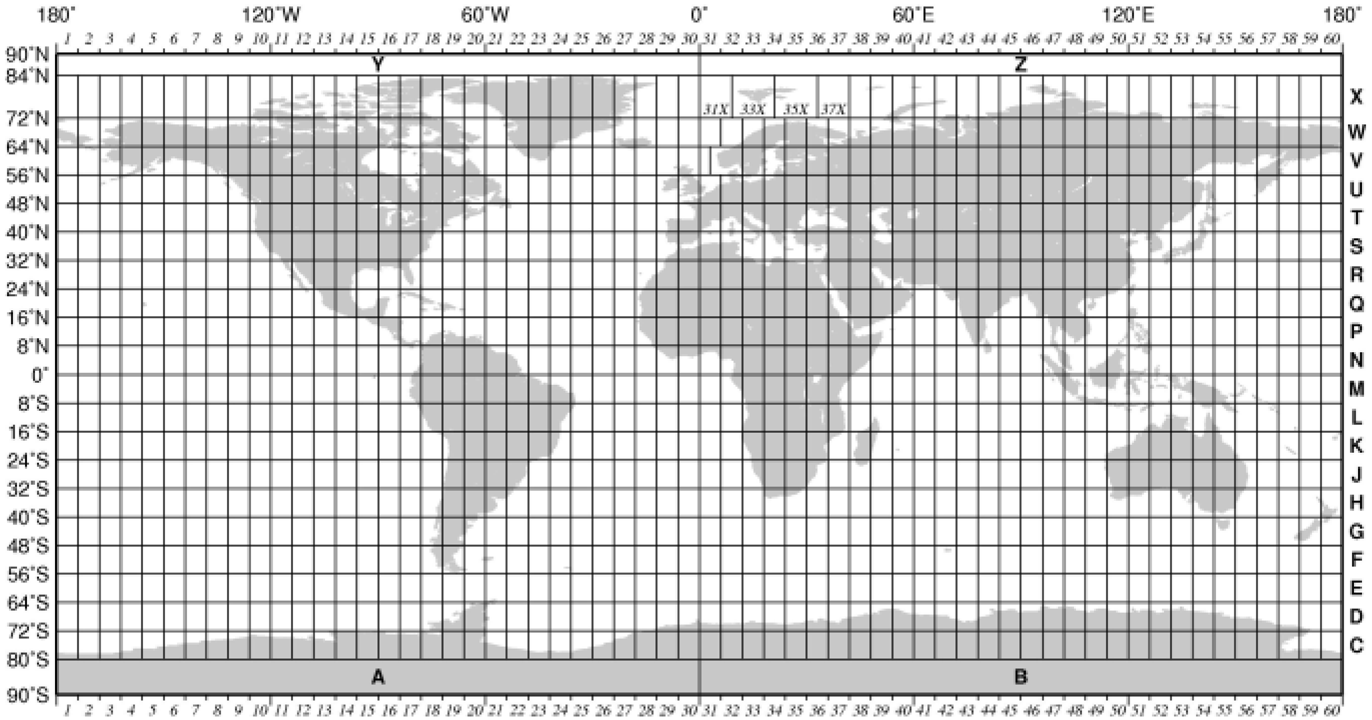


Transverse Mercator (USGS)

Cylindrical Projections

Universal Transverse Mercator Projection

- Subset of the Transverse Mercator Projection
- Adopted by the US Army for maps
- Globe divided into 60 zones (84S-84N)
- Each UTM zone has unique central meridian



Universal Transverse Mercator (created by GMT)

Cylindrical Projections

Universal Transverse Mercator Projection

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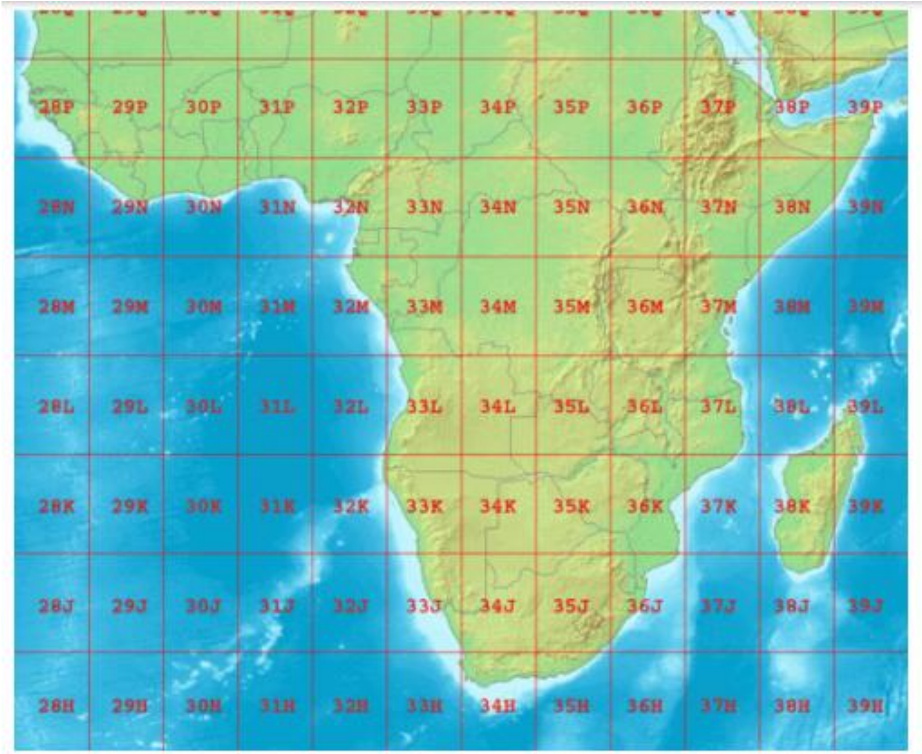


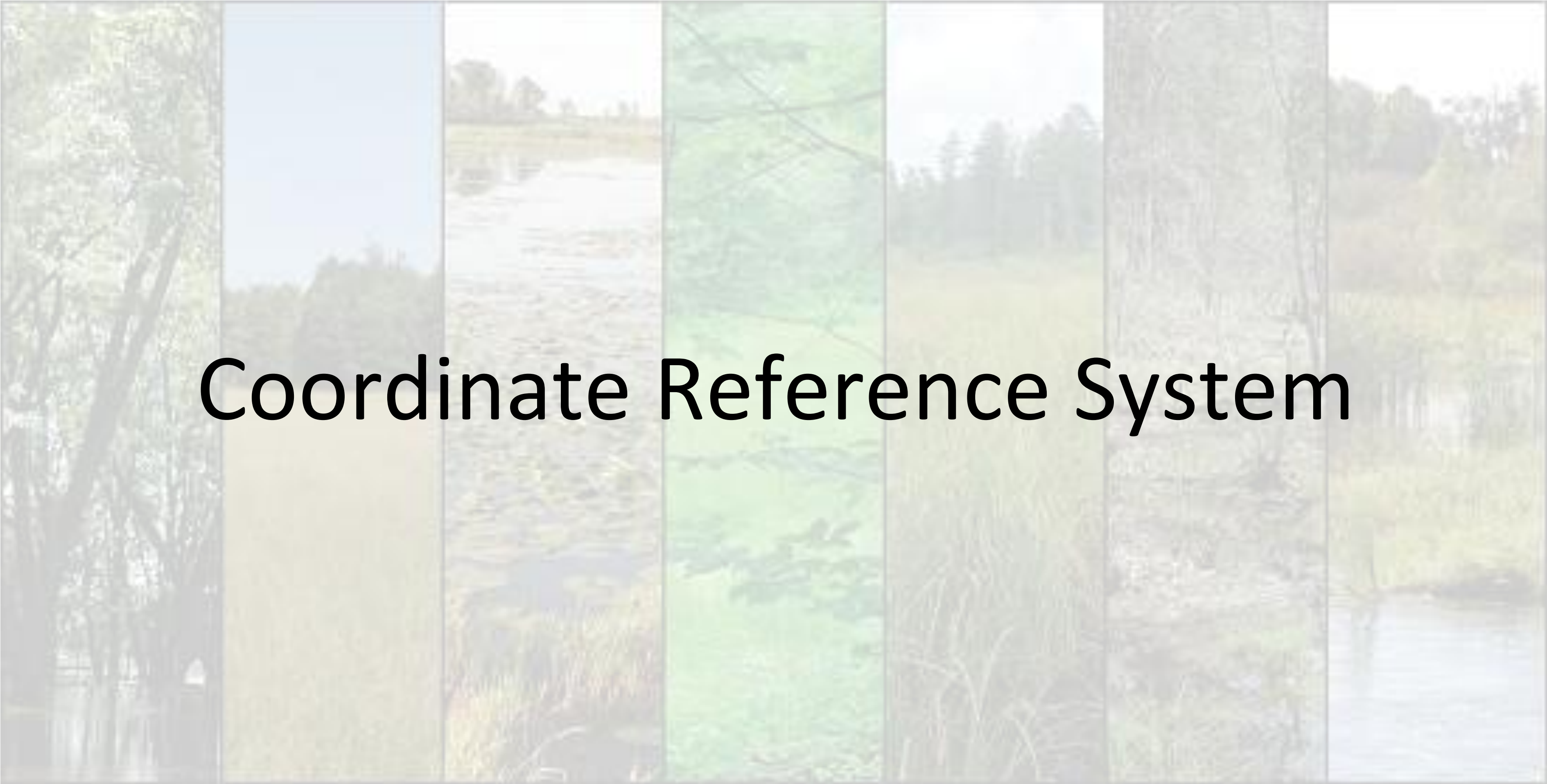
UTM zones of Africa: Map of Africa, showing the latitude and longitude zones of the en:Universal Transverse Mercator coordinate system, from 28H to 39S.

Wikimedia Commons, 2022

Projections

Projection characteristics:

- Groups: conformal (true shape/angle), equal-area (true area), equidistant (true distances), true direction
- Types: Cylindrical, Azimuthal (planar), Conic, Polyconic
- No perfection, every projection is distorted
- Different projections are suitable for different applications and geographic areas/extents



Coordinate Reference System

Terminology – Geographic Coordinates vs. CRS

It is important to know the difference between the following terms (even though they sound all so similar):

- *Geographic Coordinate System*: Not a projection, but the **spherical** coordinate system of the Earth
- *Coordinate Reference System (CRS):* Describes a projection, transforming spherical data (3D) into a **planar** system (2D)

A CRS consists of:

- *Geodetic datum*, the *geodetic reference system*: placing reference locations on the Earth's sphere and thereby defines the ellipsoid approximating the sphere and how it is placed (e.g., the popular WGS84)
- *Coordinate System*: projecting a coordinate grid of some sort onto the geodetic reference system
- *Units*: spatial measure used by the CRS, e.g., meters, feets, degrees

Which CRS should I use?

- **Global Scale**: e.g., Sinusoidal Equal Area
- **Continental Scale**: e.g., Lambert Azimuthal Equal Area
- **Small Scale**: e.g., Universal Transverse Mercator (UTM) with WGS84, Lambert Conformal Conic

Which CRS should I use?

Choice depends on:

- **Your aim**: Where is your research area) How large does it spread? Which attributes do you want to preserve/distort?
- **Your data**: With which CRS are your data delivered? Is it worth transforming them? Which common CRS for all your data imposes the least added inaccuracies?
- **Your project partners**: With which CRS are they working? What CRS should your project be delivered in, e.g., to ease interpretability?

CRS – Implementation example I

Human-readable CRS designation:
Universal Transverse Mercator (UTM) World Geodetic System 1984 (WGS84) Zone 32N

Authority ID:
EPSG: 32632

```
+proj=utm +zone=32 +datum=WGS84 +units=m +no_defs
```

CRS – Implementation example II

Well-known text (WKT):

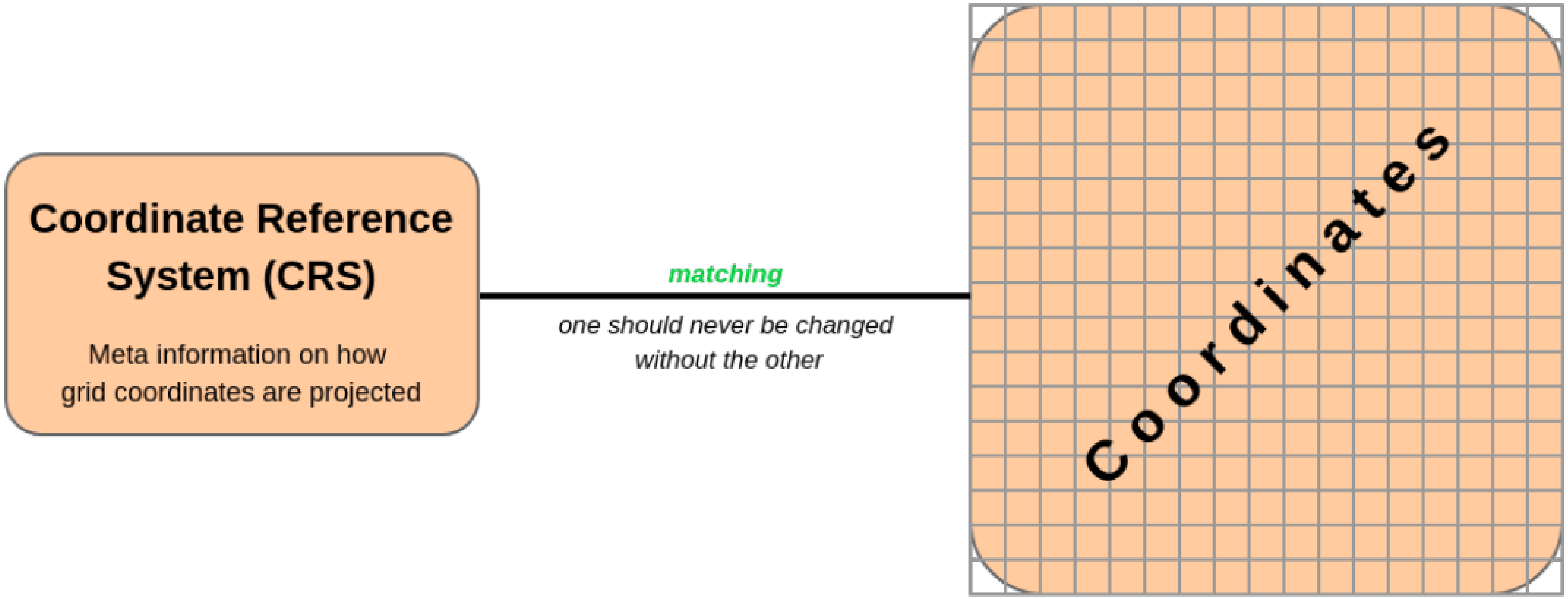
```
PROJCRS["WGS 84 / UTM zone 32N",
    BASEGEOGCRS["WGS 84",
        DATUM["World Geodetic System 1984",
            ELLIPSOID["WGS 84",6378137,298.257223563,
                LENGTHUNIT["metre",1]]],
        PRIMEM["Greenwich",0,
            ANGLEUNIT["degree",0.0174532925199433]],
        ID["EPSG",4326]],
    CONVERSION["UTM zone 32N",
        METHOD["Transverse Mercator",
            ID["EPSG",9807]],
        PARAMETER["Latitude of natural origin",0,
            ANGLEUNIT["degree",0.0174532925199433],
            ID["EPSG",8801]],
        PARAMETER["Longitude of natural origin",9,
            ANGLEUNIT["degree",0.0174532925199433],
            ID["EPSG",8802]],
        PARAMETER["Scale factor at natural origin",0.9996,
            SCALEUNIT["unity",1],
            ID["EPSG",8805]],
```

CRS – Implementation example III

```
        PARAMETER["False easting",500000,
            LENGTHUNIT["metre",1],
            ID["EPSG",8806]],
        PARAMETER["False northing",0,
            LENGTHUNIT["metre",1],
            ID["EPSG",8807]]],
    CS[Cartesian,2],
        AXIS["(E)",east,
            ORDER[1],
            LENGTHUNIT["metre",1]],
        AXIS["(N)",north,
            ORDER[2],
            LENGTHUNIT["metre",1]],
    USAGE[
        SCOPE["unknown"],
        AREA["World – N hemisphere – 6°E to 12°E – by country"],
        BBOX[0,6,84,12]],
    ID["EPSG",32632]]
```

CRS and coordinates

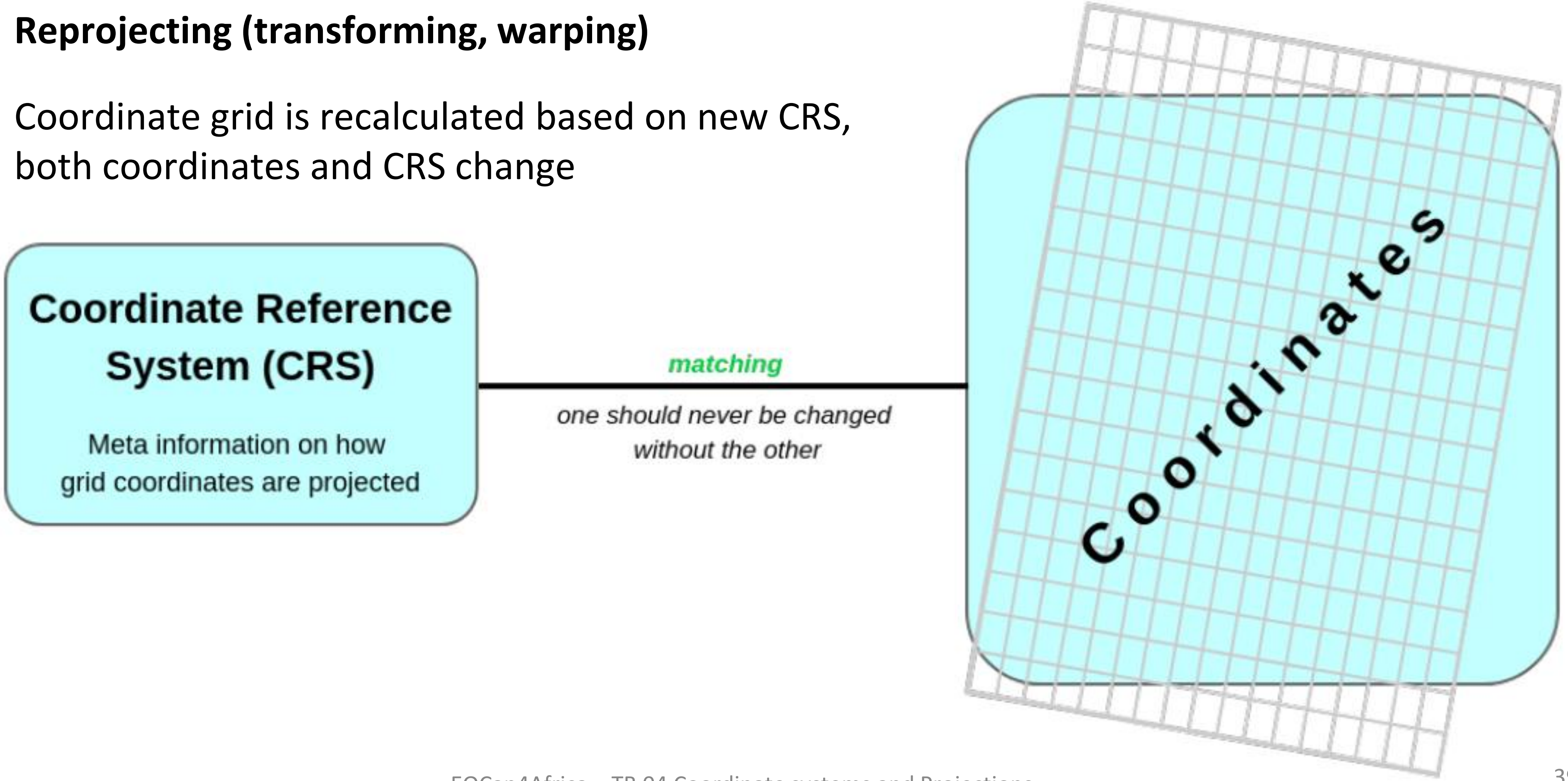
Original coordinates and matching CRS



CRS and coordinates

Reprojecting (transforming, warping)

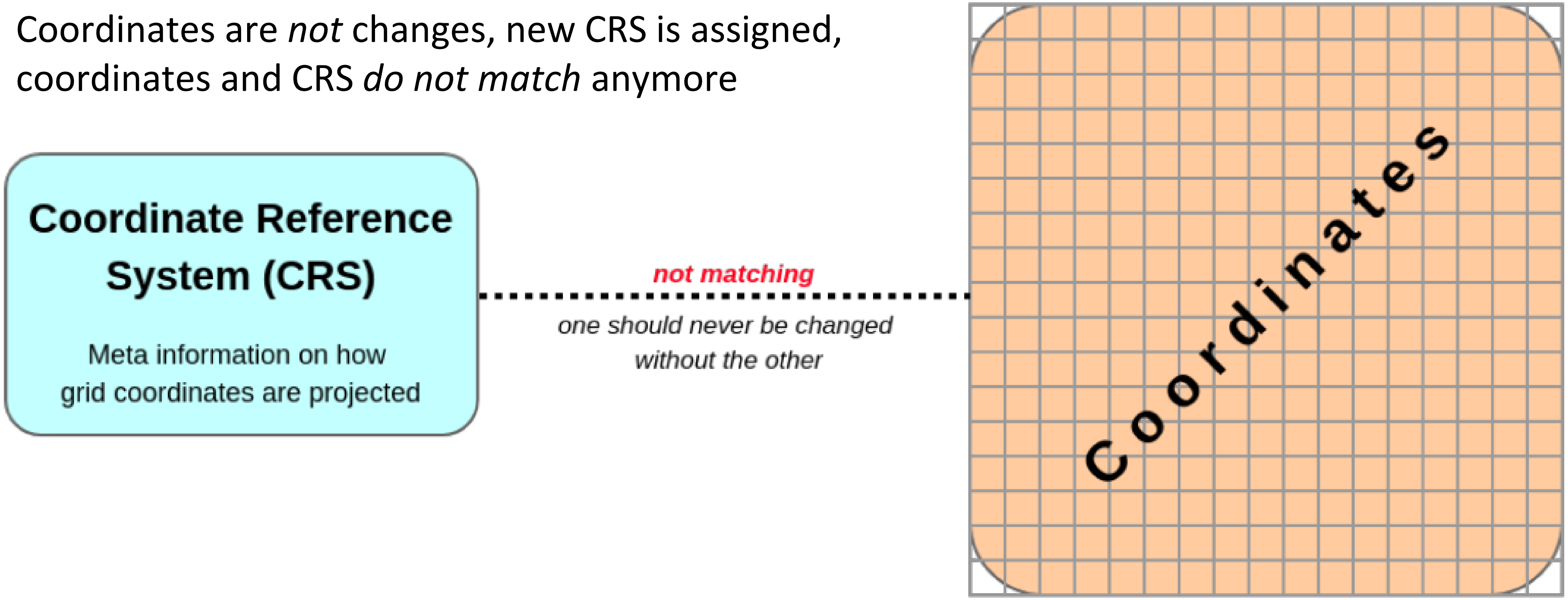
Coordinate grid is recalculated based on new CRS, both coordinates and CRS change



CRS and coordinates

Assigning a new CRS

Coordinates are *not* changes, new CRS is assigned, coordinates and CRS *do not match* anymore



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Thank you for your attention!

Dr. Insa Otte (on behalf of the EOCap4Africa Team) and colleagues

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Recourses

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