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EOCap 4Africa

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## 4 Coordinate Reference Systems and Projections

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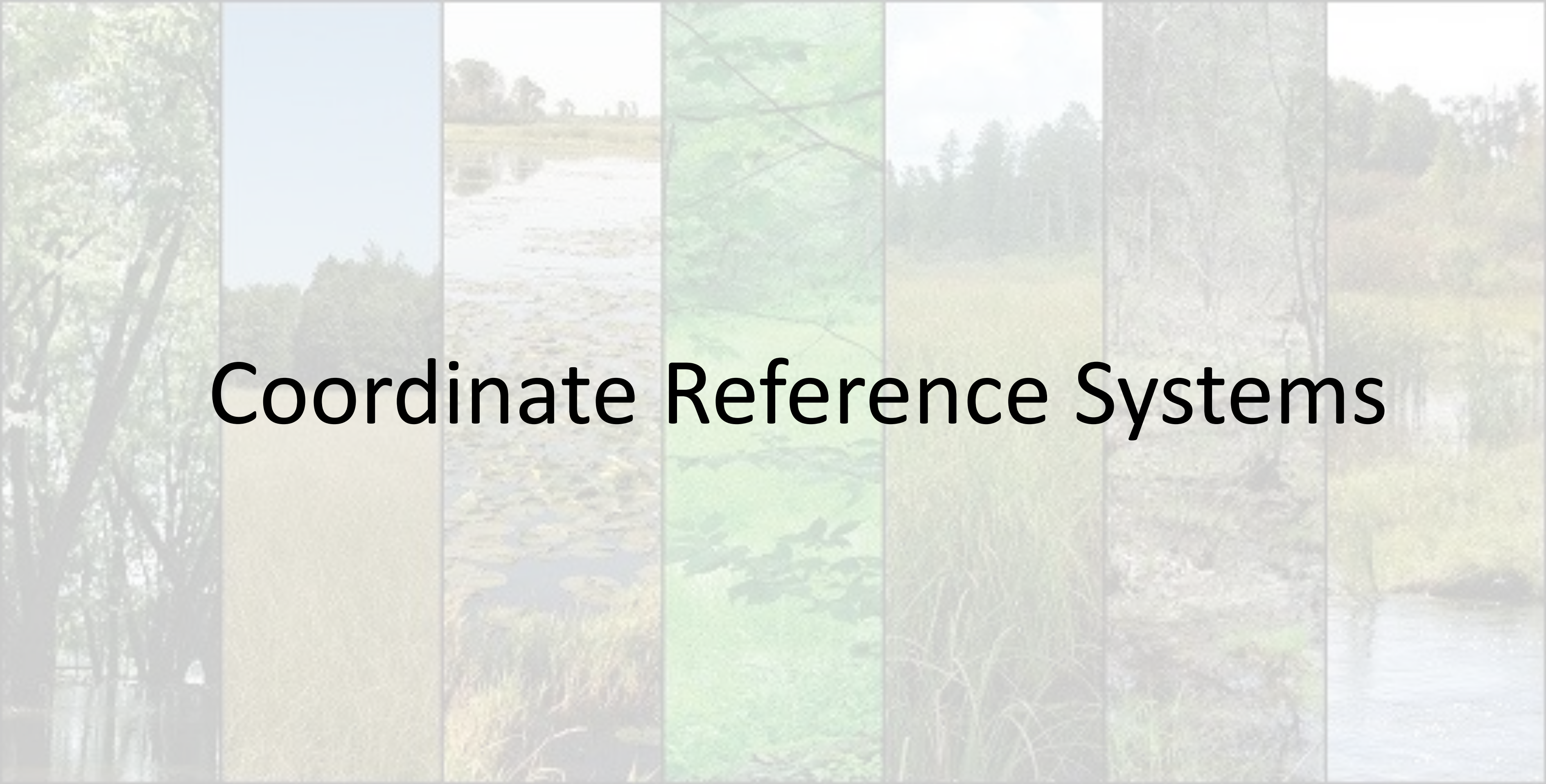
EARTH OBSERVATION RESEARCH

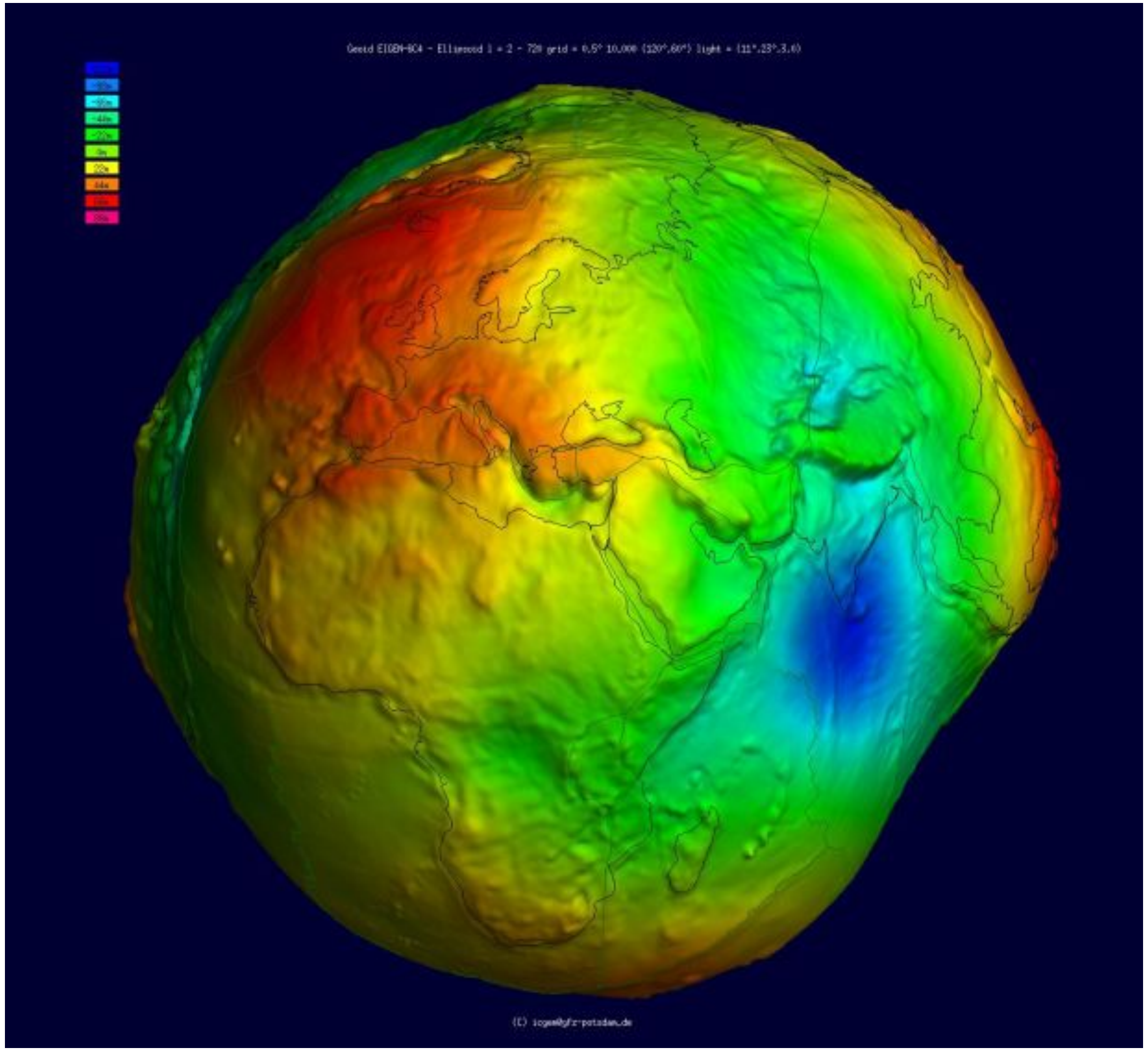


# Coordinate Reference Systems

# Geoid

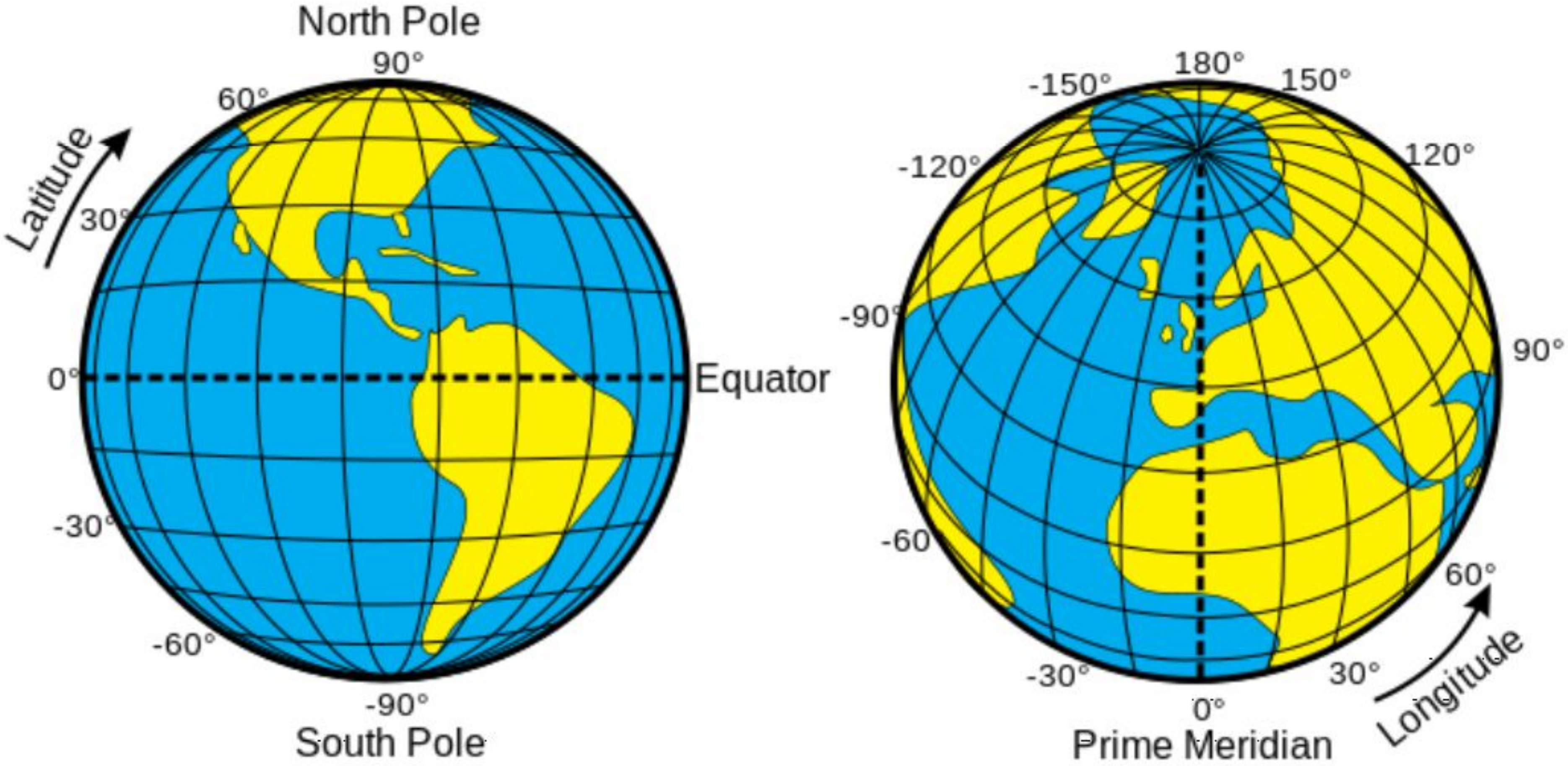
The “blue marble” – or is marble really the right term?

# Geoid



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

# Geographic Coordinate System



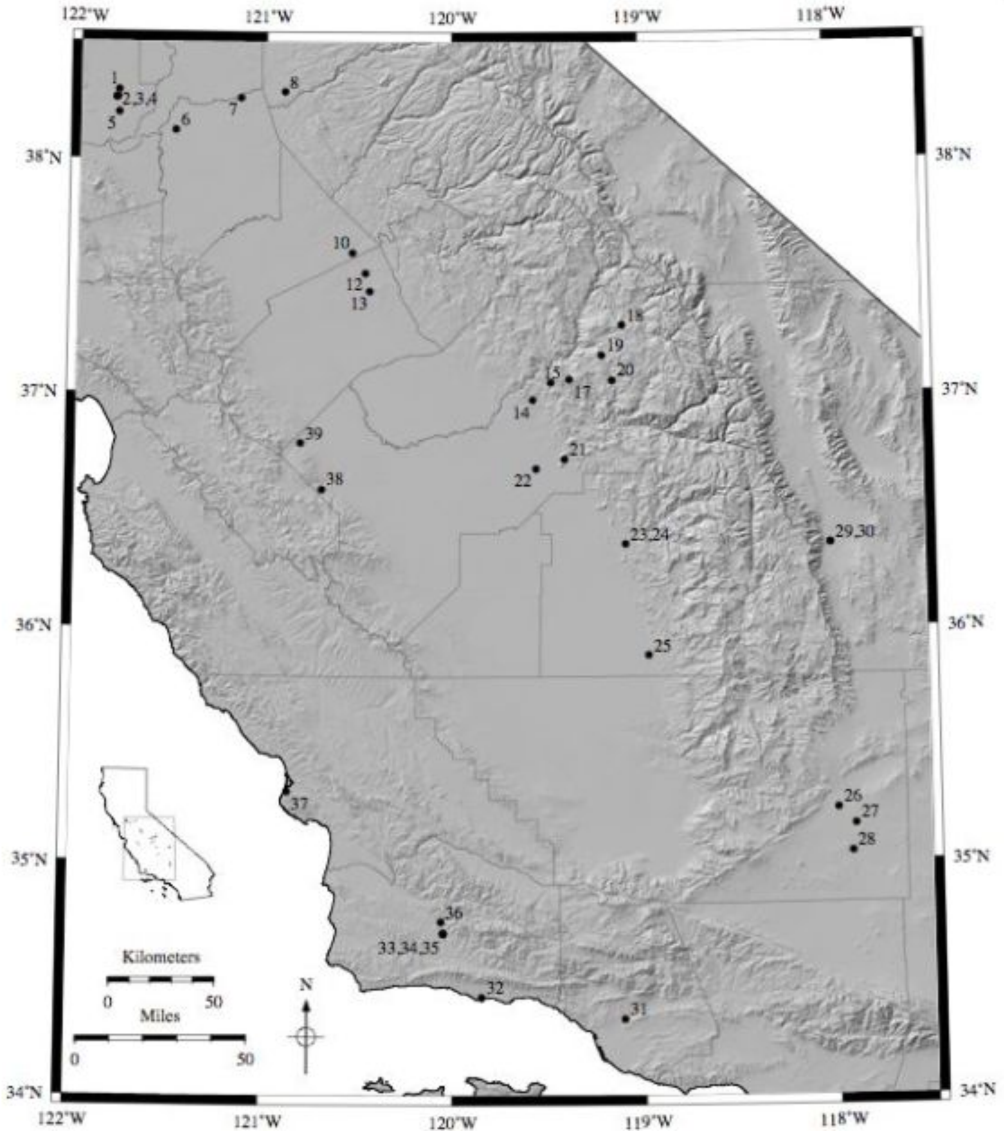

The Earth’s Geographic Coordinate System: unlike cartesian systems it is not planar, but spherical and uses angles (latitudes and longitudes) to describe locations. Wikimedia Commons, 2022

# 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

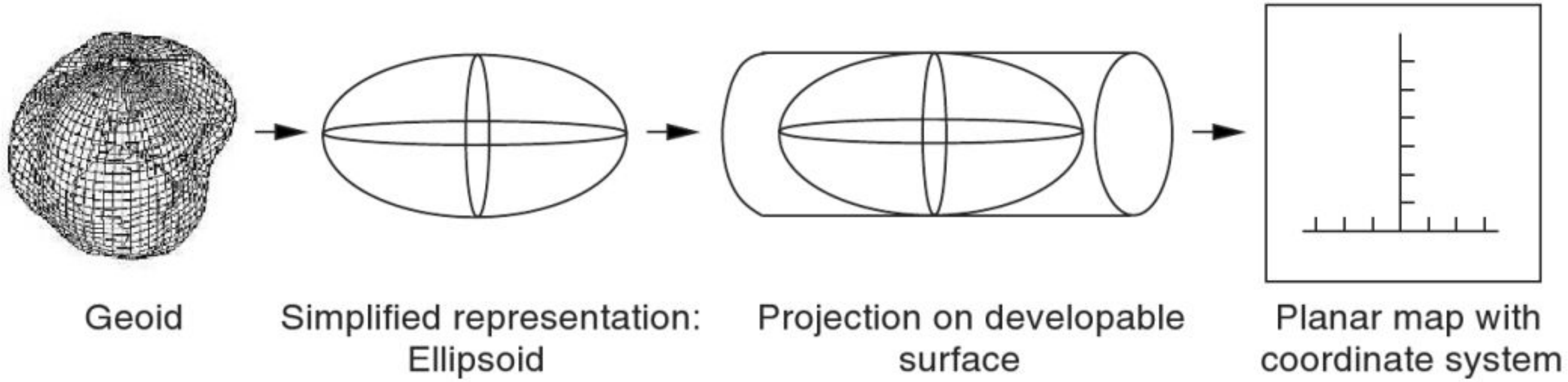



The Geographic Coordinate System is using 360 longitudes and 180 latitudes and uses the following systems:

- 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)

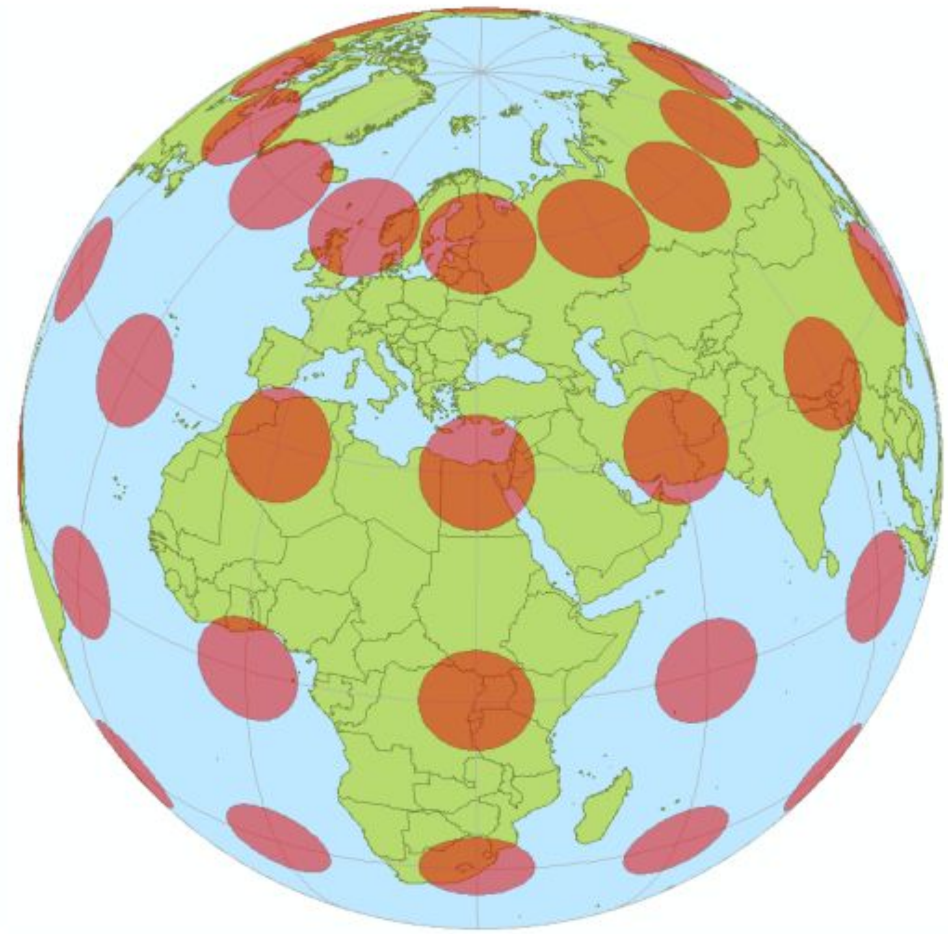
# What is a projection?

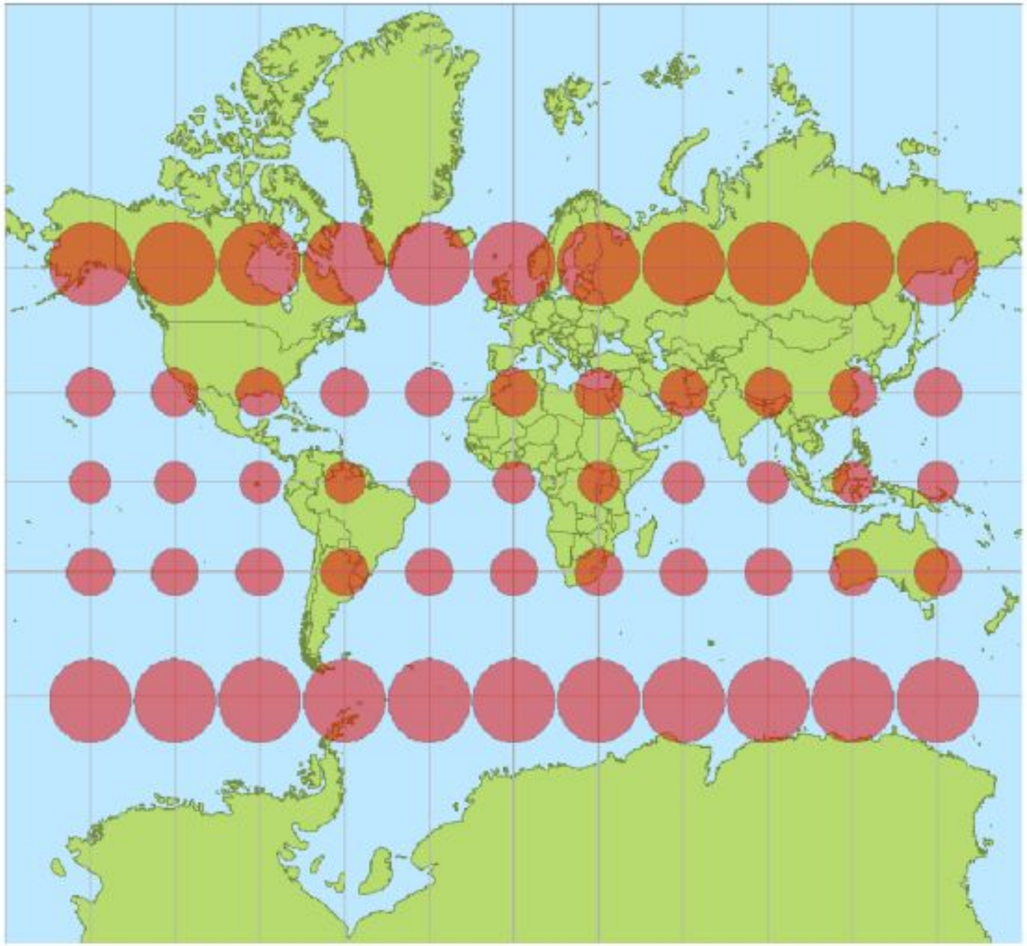
# Projecting




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

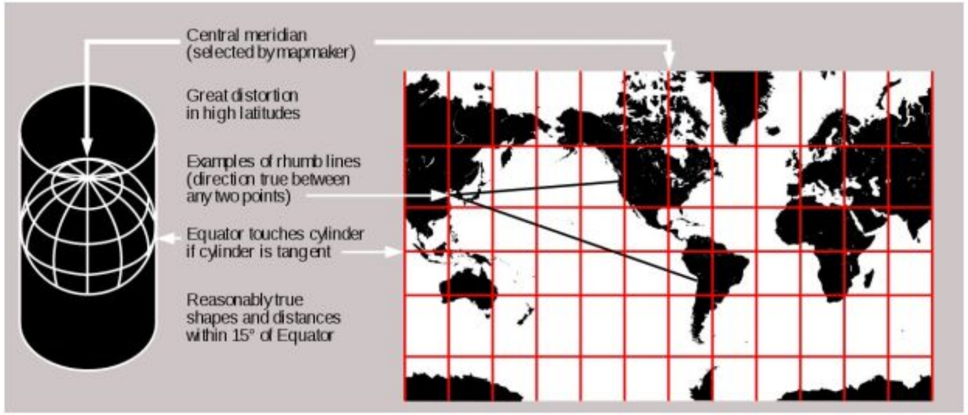
# Projecting – why?

- 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

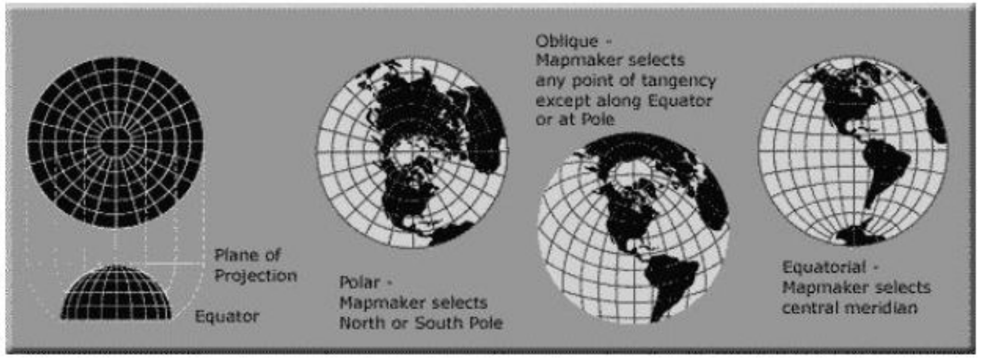
# Projecting – What kind of projections exist?

- **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

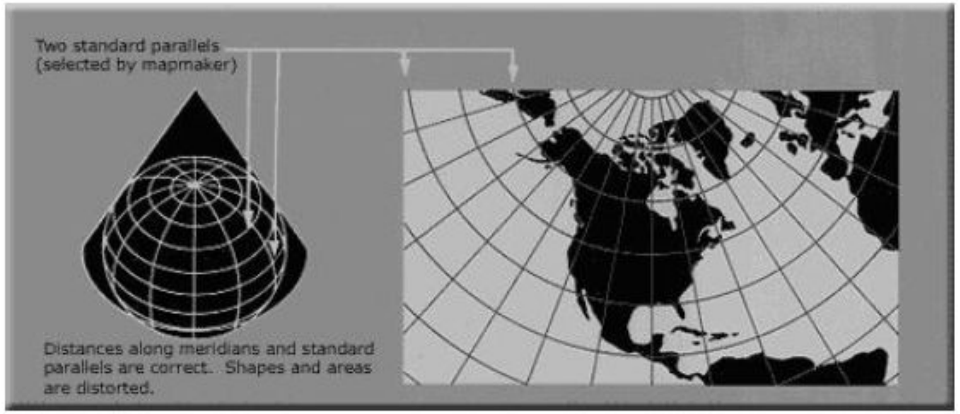



Cylindrical

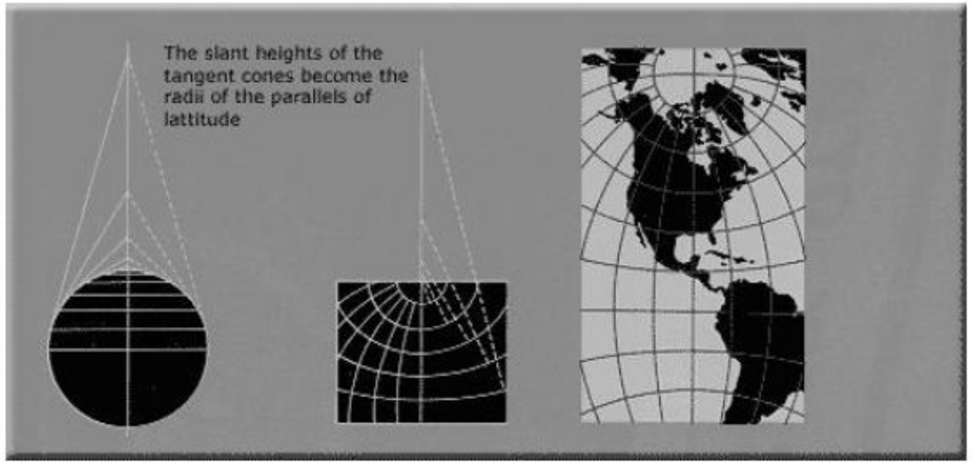



Azimuthal (planar)

# Projecting – Different ways




Conic

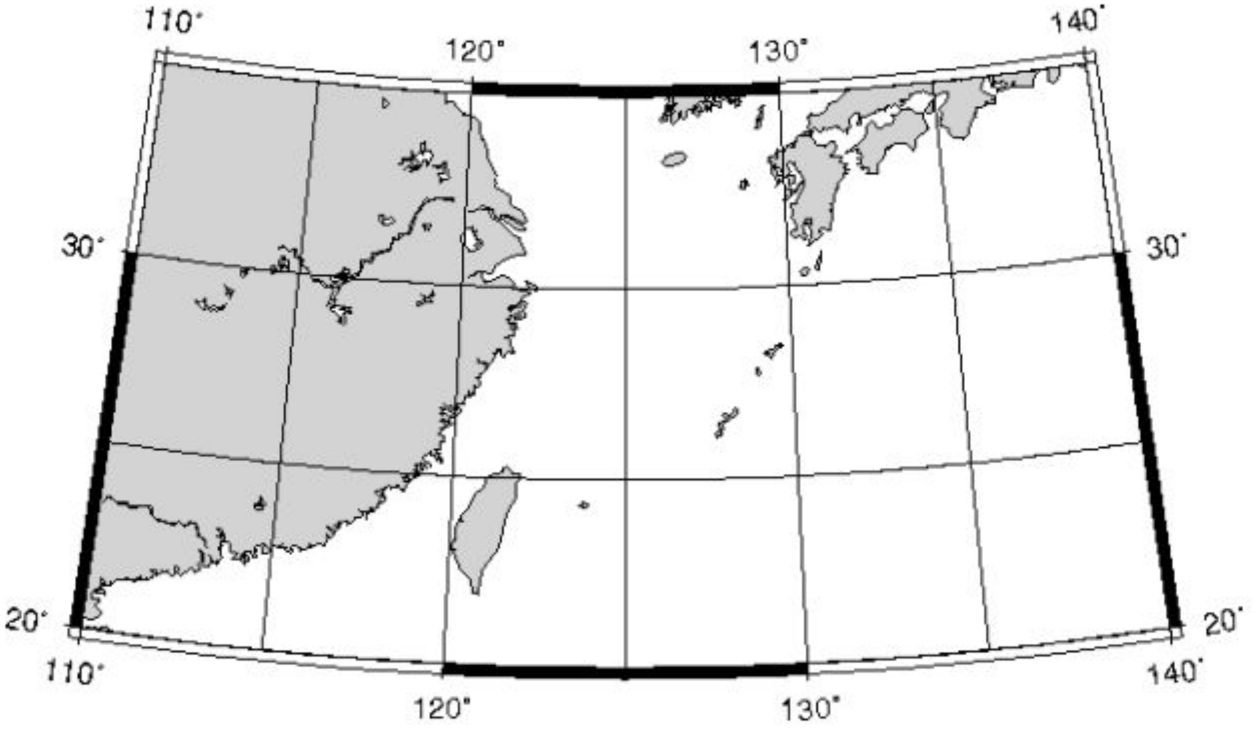



Polyconic

# 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

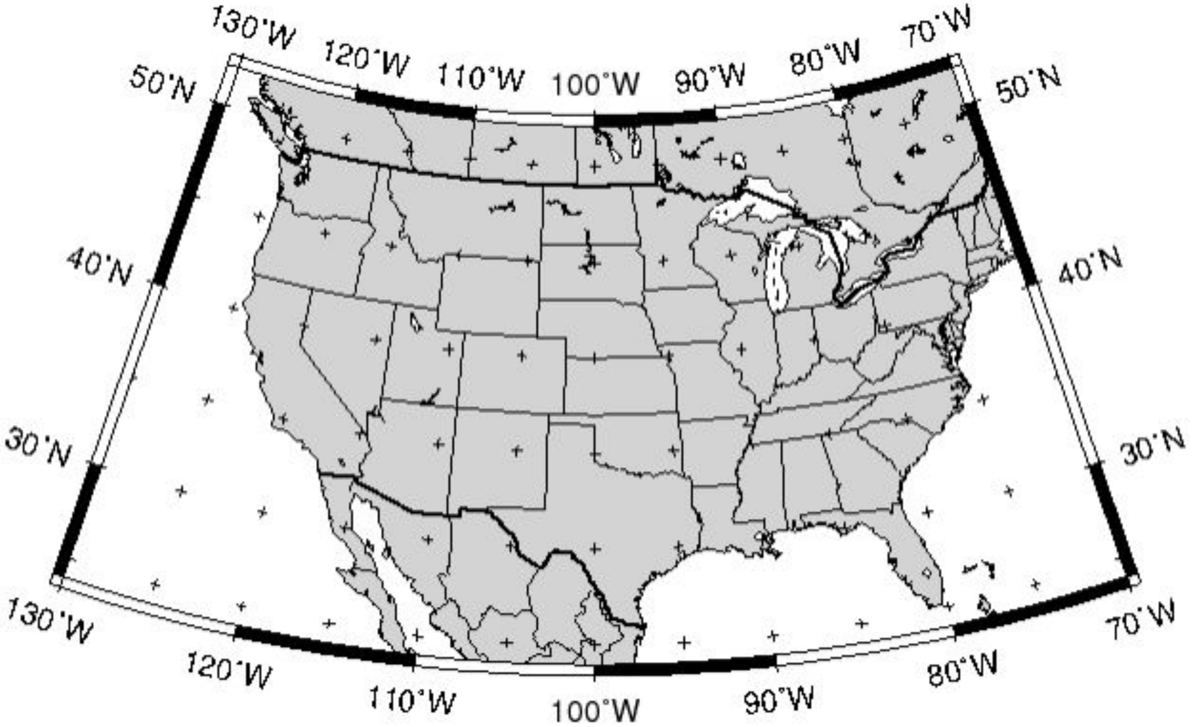



Albers Conic Equal Area (created by GMT)

# 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

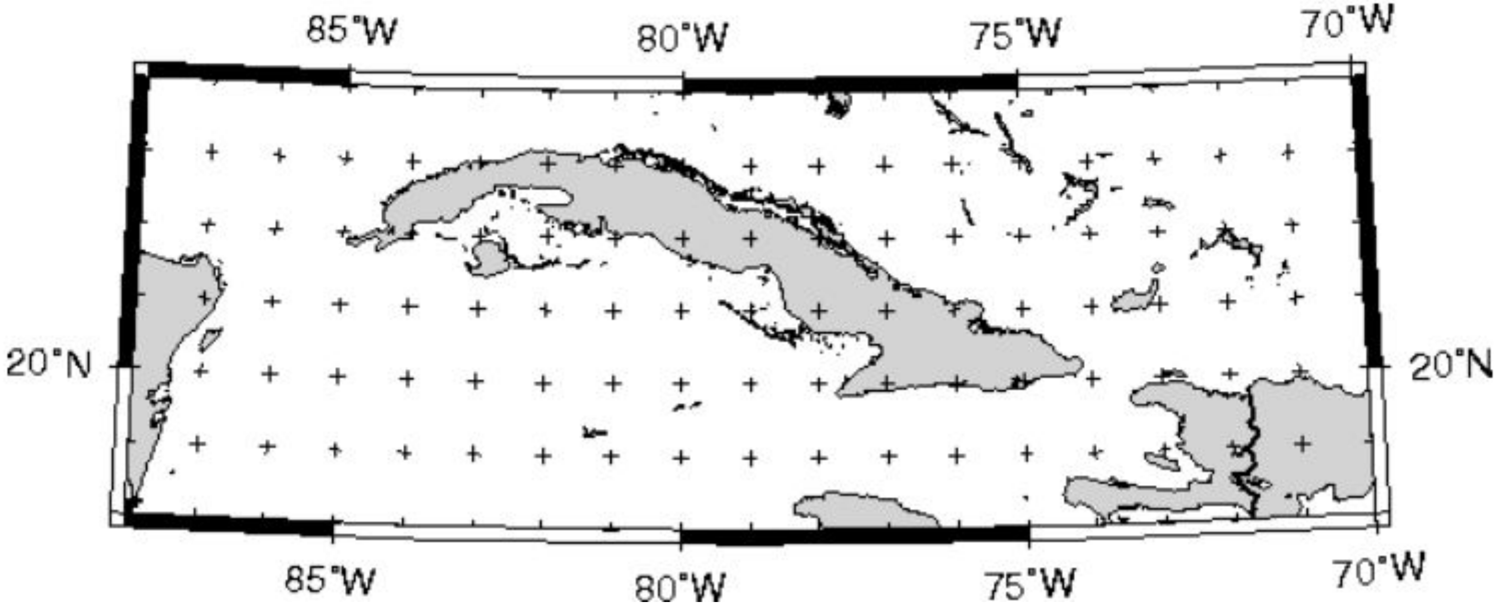



Lambert Conic Conformal (created by GMT)

# 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**

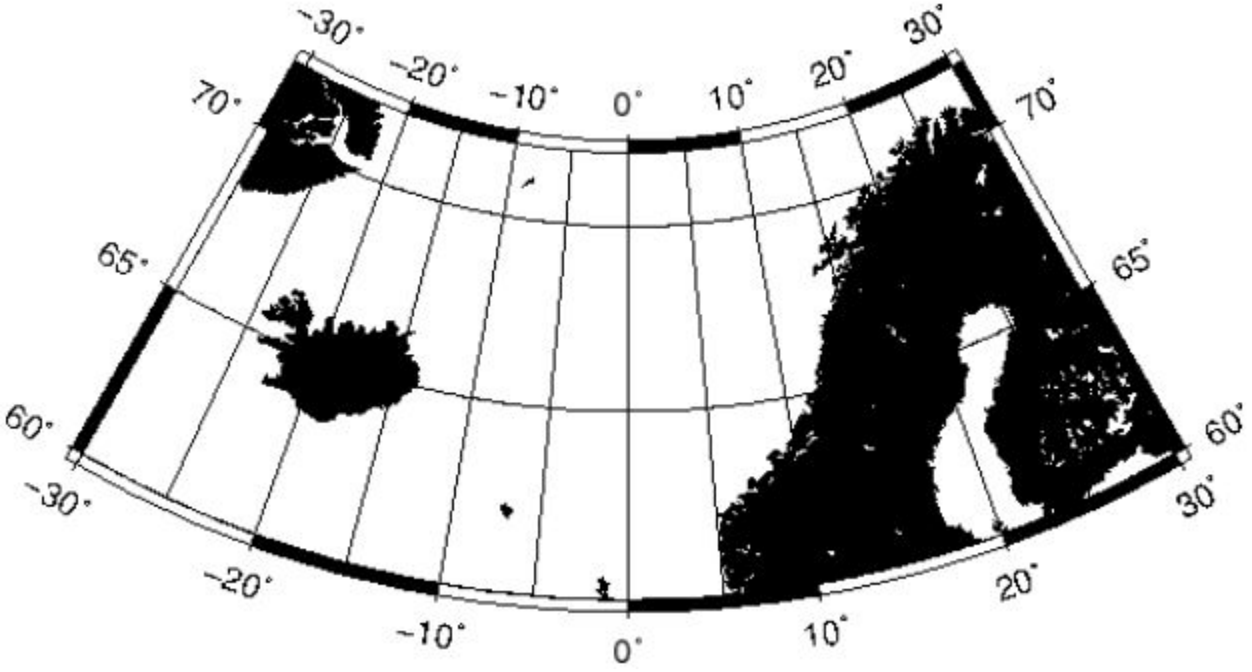
- Developed in 1772 by Lambert
- Used for mapping large regions (e.g., continents)
- It is an azimuthal, equal-area projection but not perspective

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**

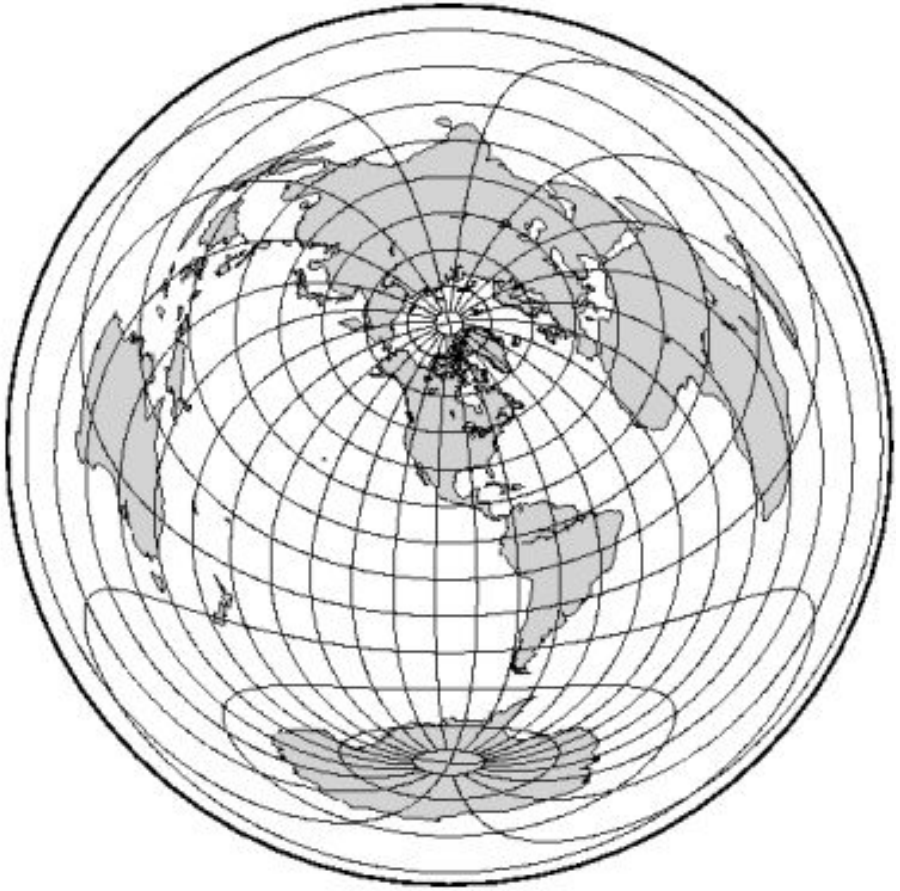
- Perspective from an infinite distance
- Used for appearance of the earth from space
- Much distortion is introduced

Orthographic (created by GMT)

# Azimuthal Projections

**Equidistant Azimuthal Projection**

- Direction from the center is true
- Several centuries old

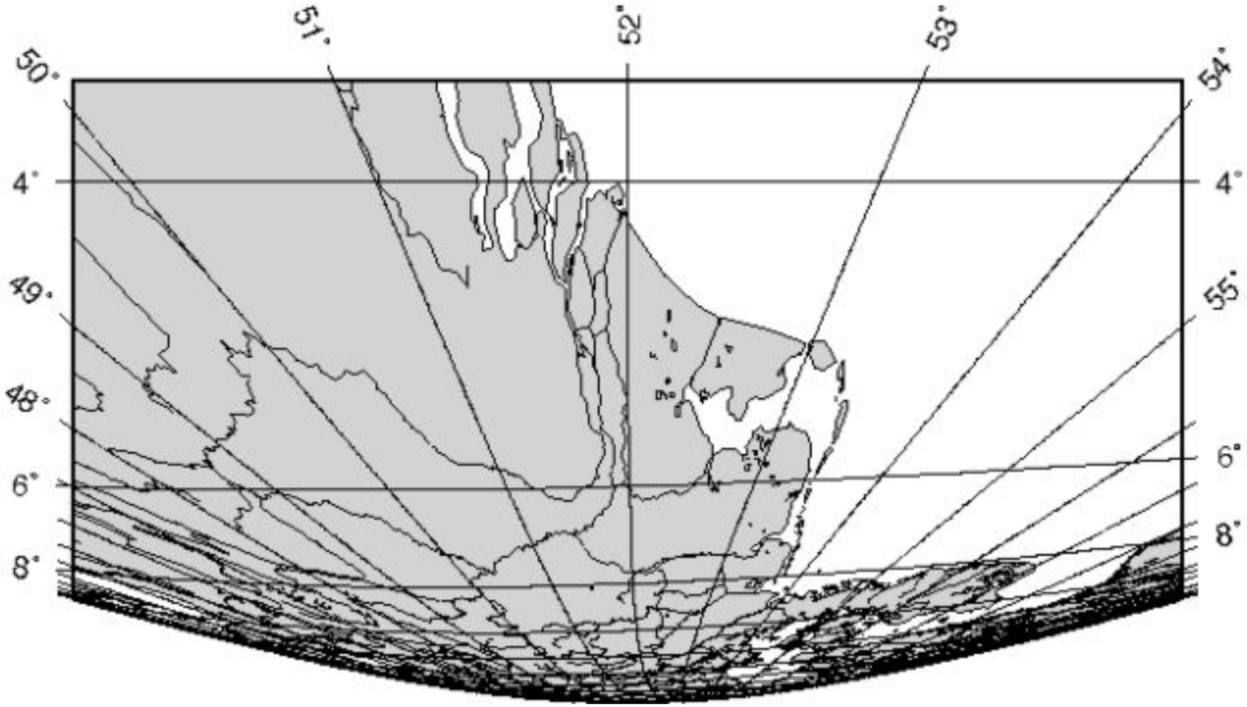


Equidistant Azimuthal (created by GMT)

# Azimuthal Projections

**Perspective Projection**

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

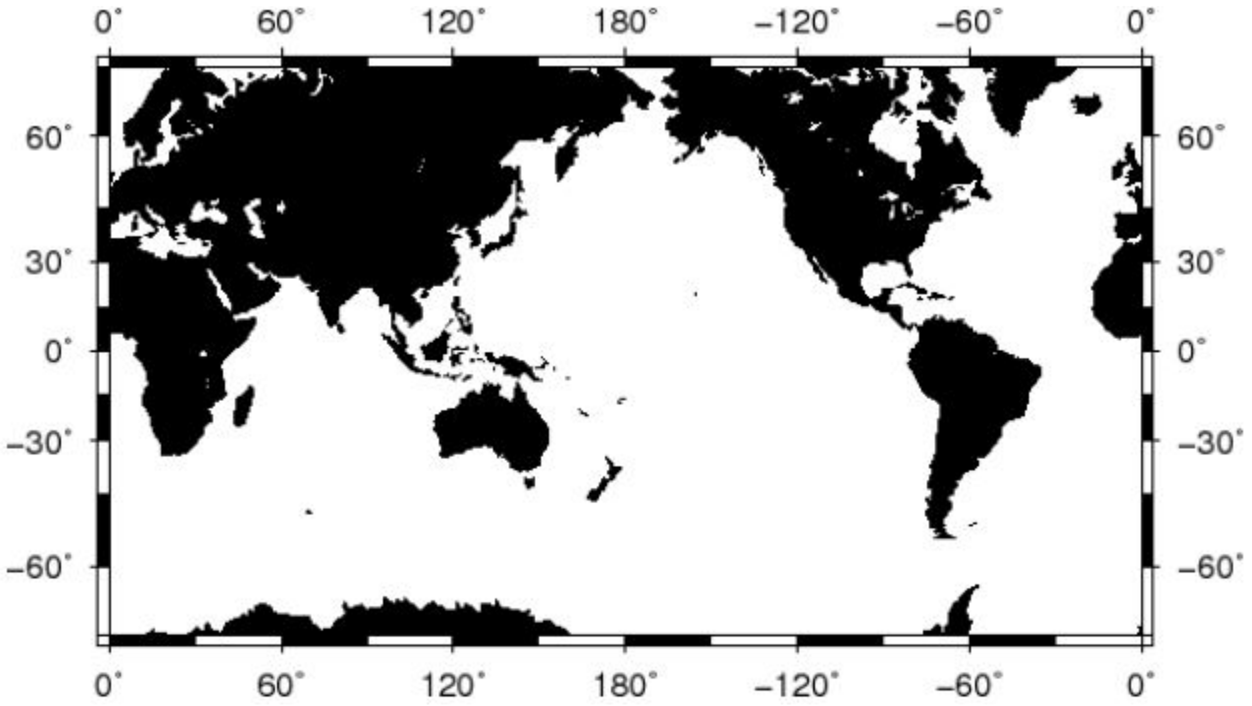



Perspective (created by GMT)

# Cylindrical Projections

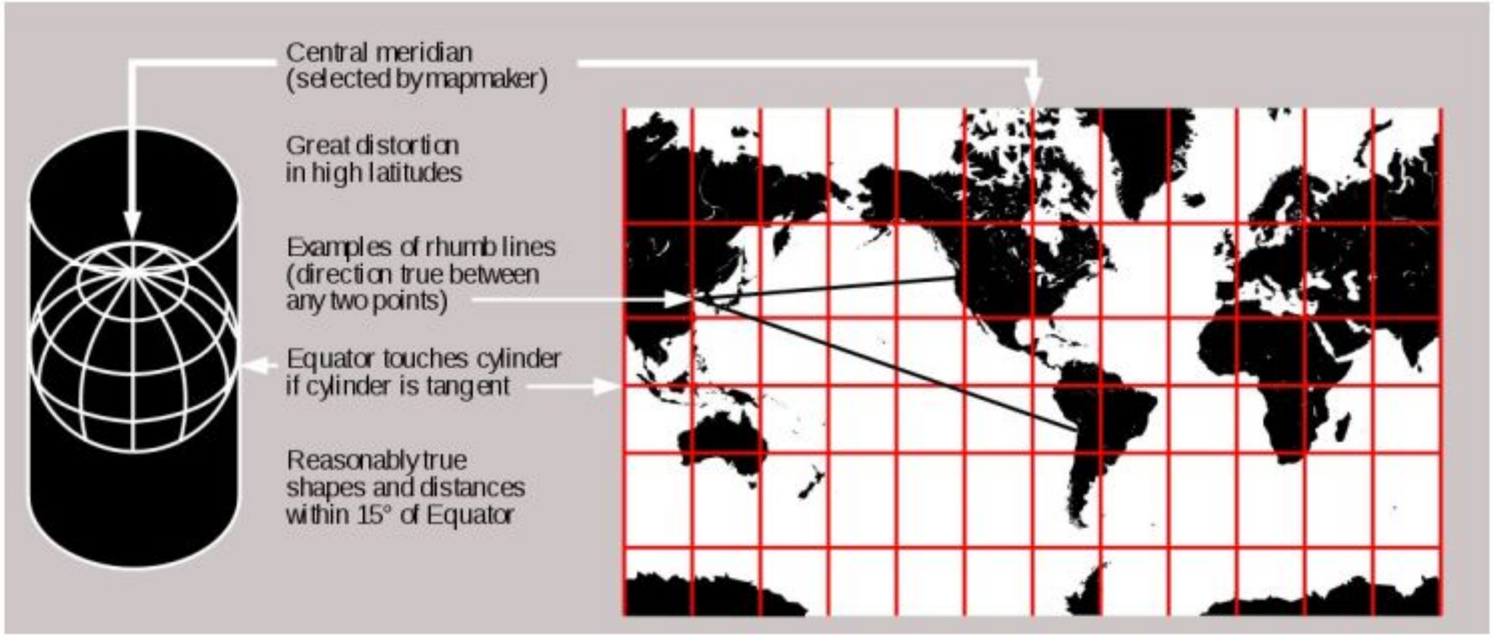
**Mercator Projection**

- 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

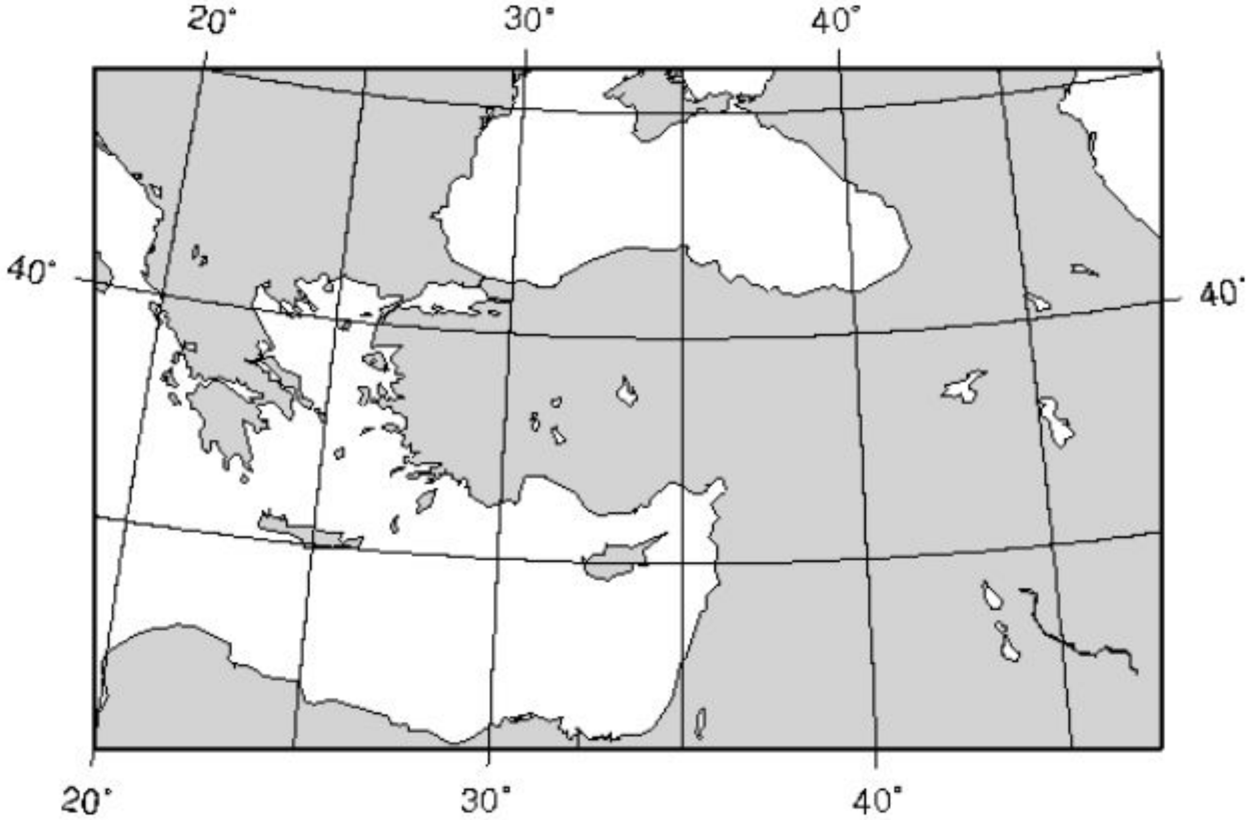



Mercator (USGS)

# 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
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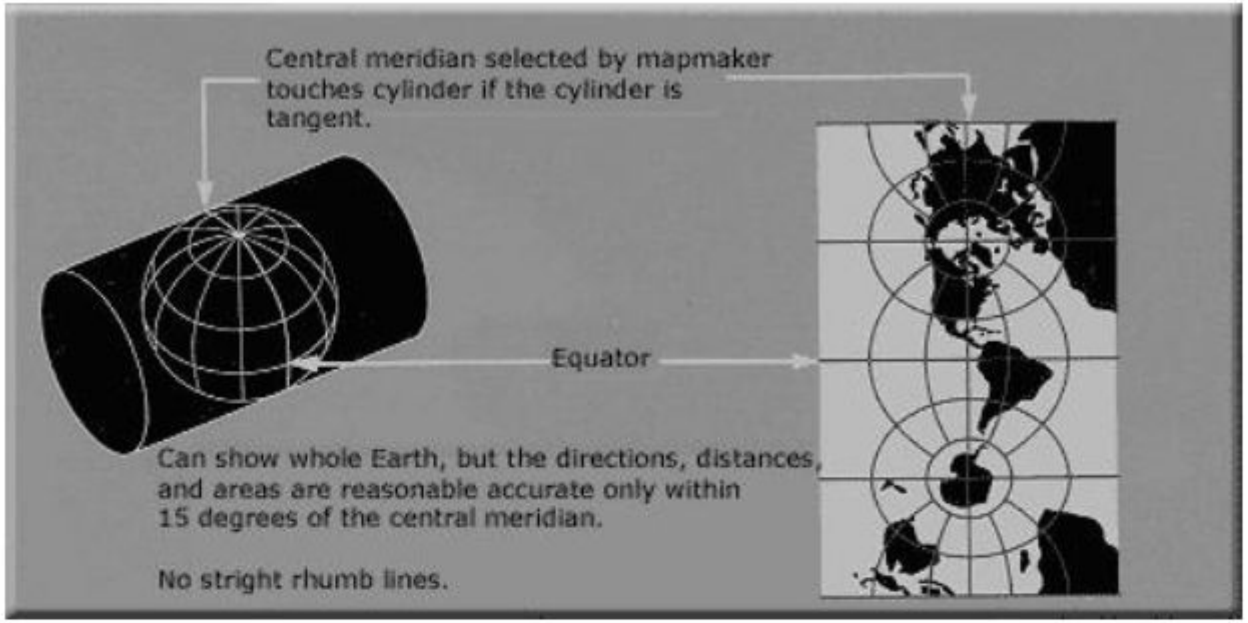
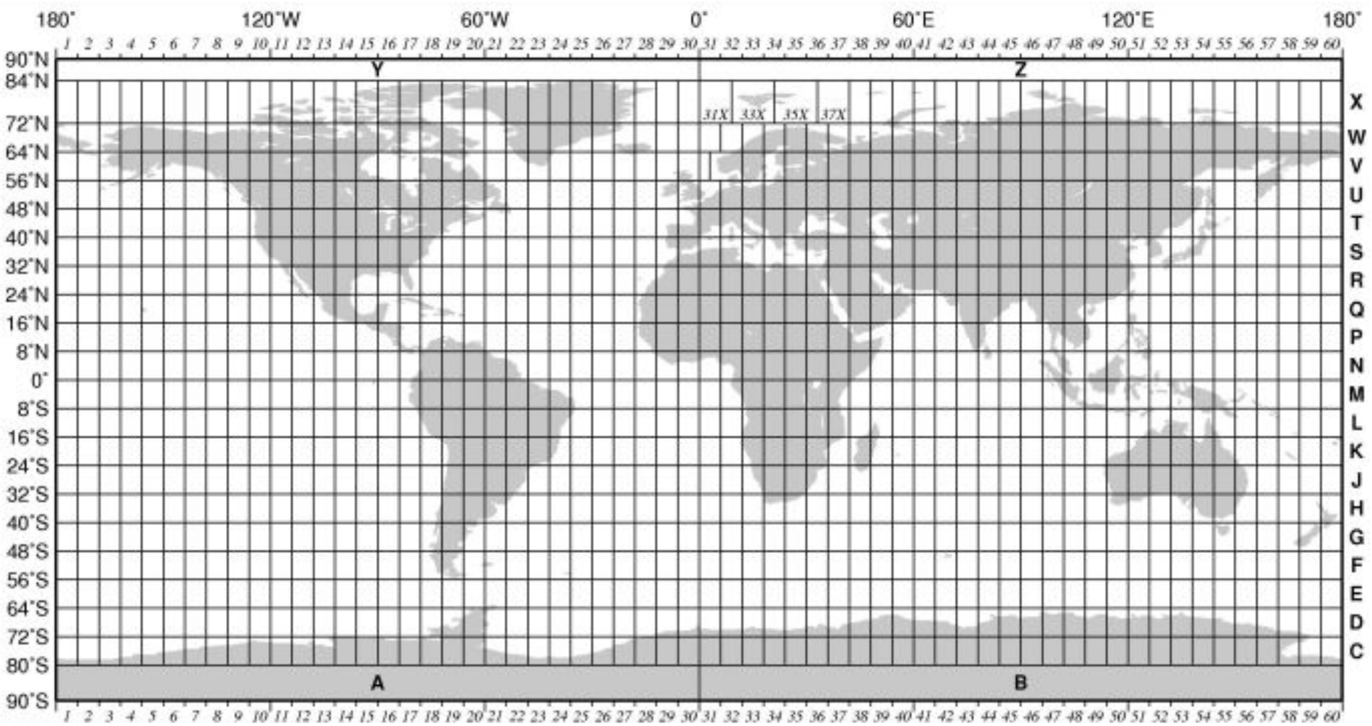



Transverse Mercator (USGS)

# 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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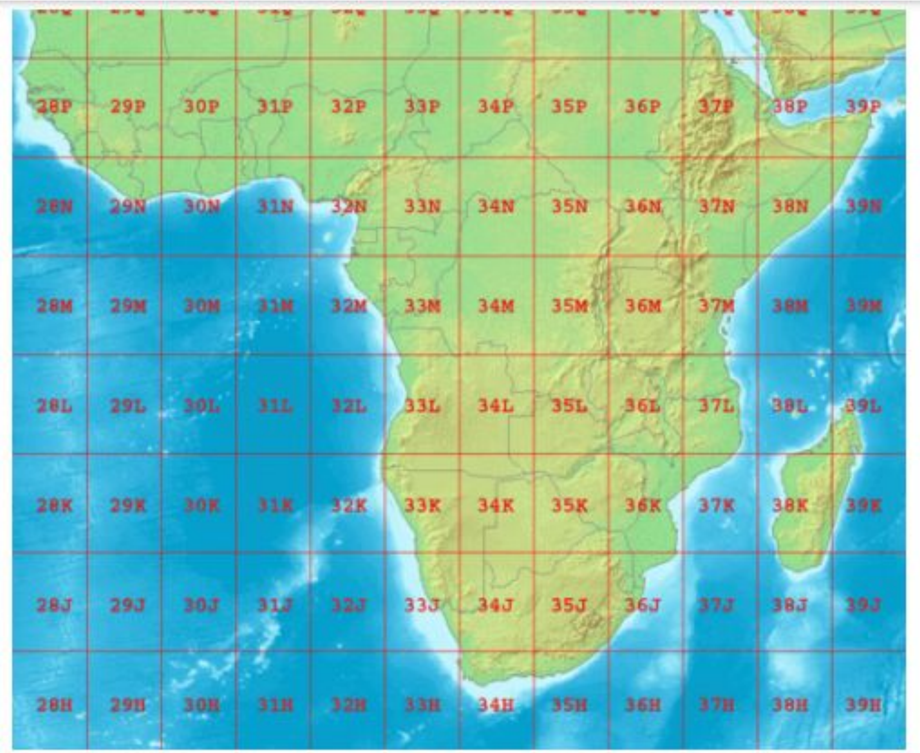
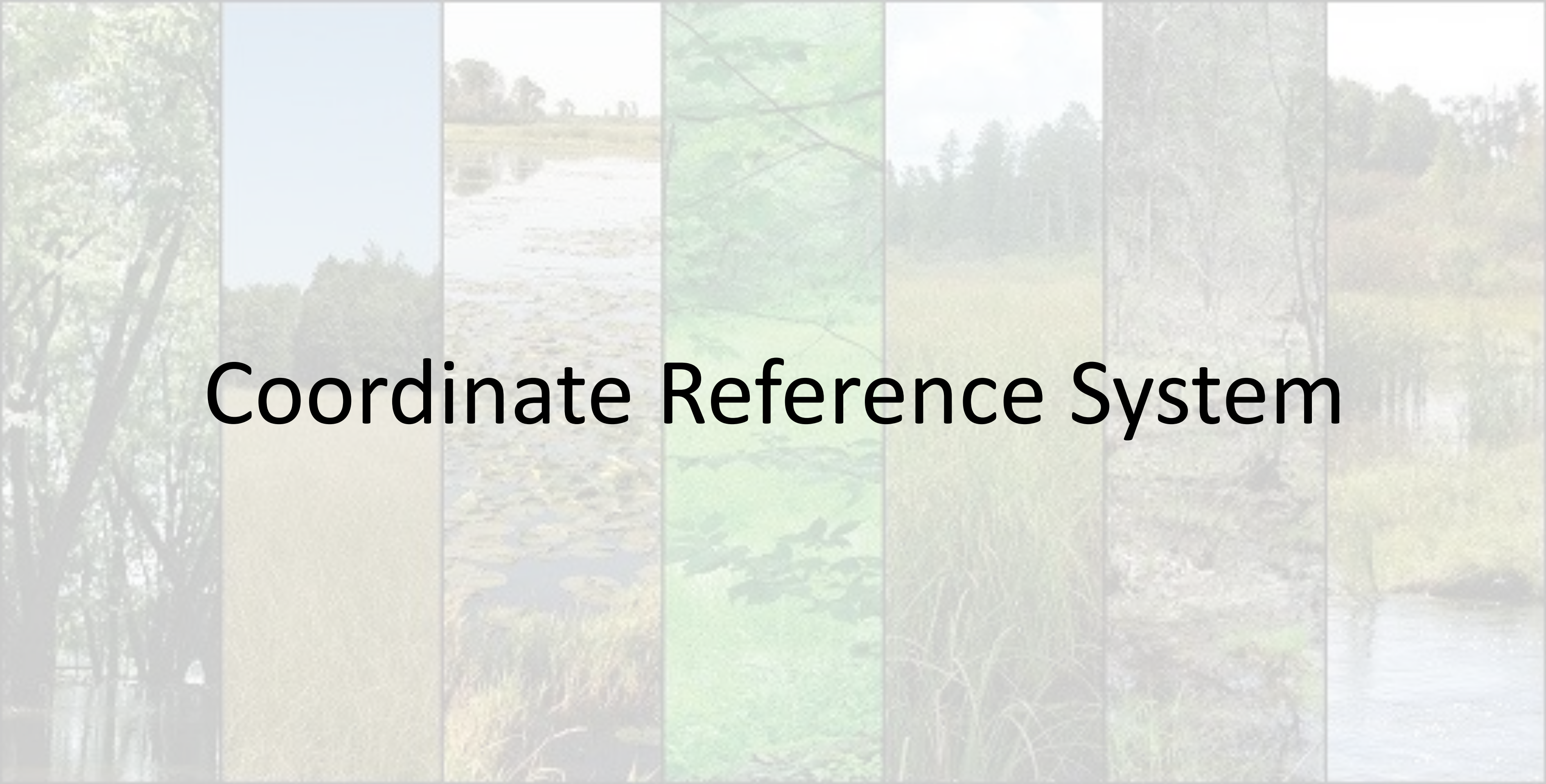



UTM zones of Africa

# 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

**Proj4 string**:

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

# CRS – Implementation example II

**Well-known text (WKT)**:

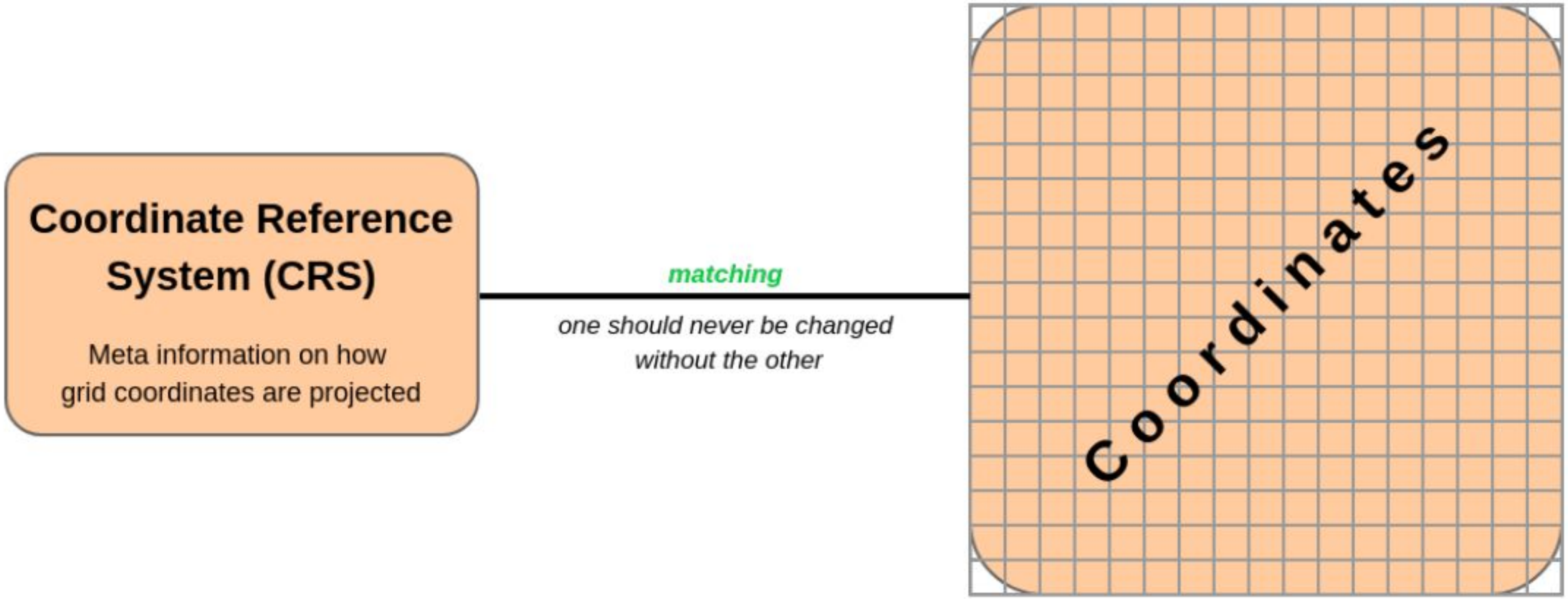
```
PROJCRS["WGS 84 / UTM zone 32N",
    BASEGEOGCRS["WGS 84",
        DATUM["World Geodetic System 1984",
            ELLIPSOID["WGS 84",6378137,298.257223563,
                LENGTHUNIT["metre",1]]],
        PRIMEM["Greenwich",0,
            ANGLEUNIT["degree",0.0174532925199433]],
        ID["EPSG",4326]],
    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

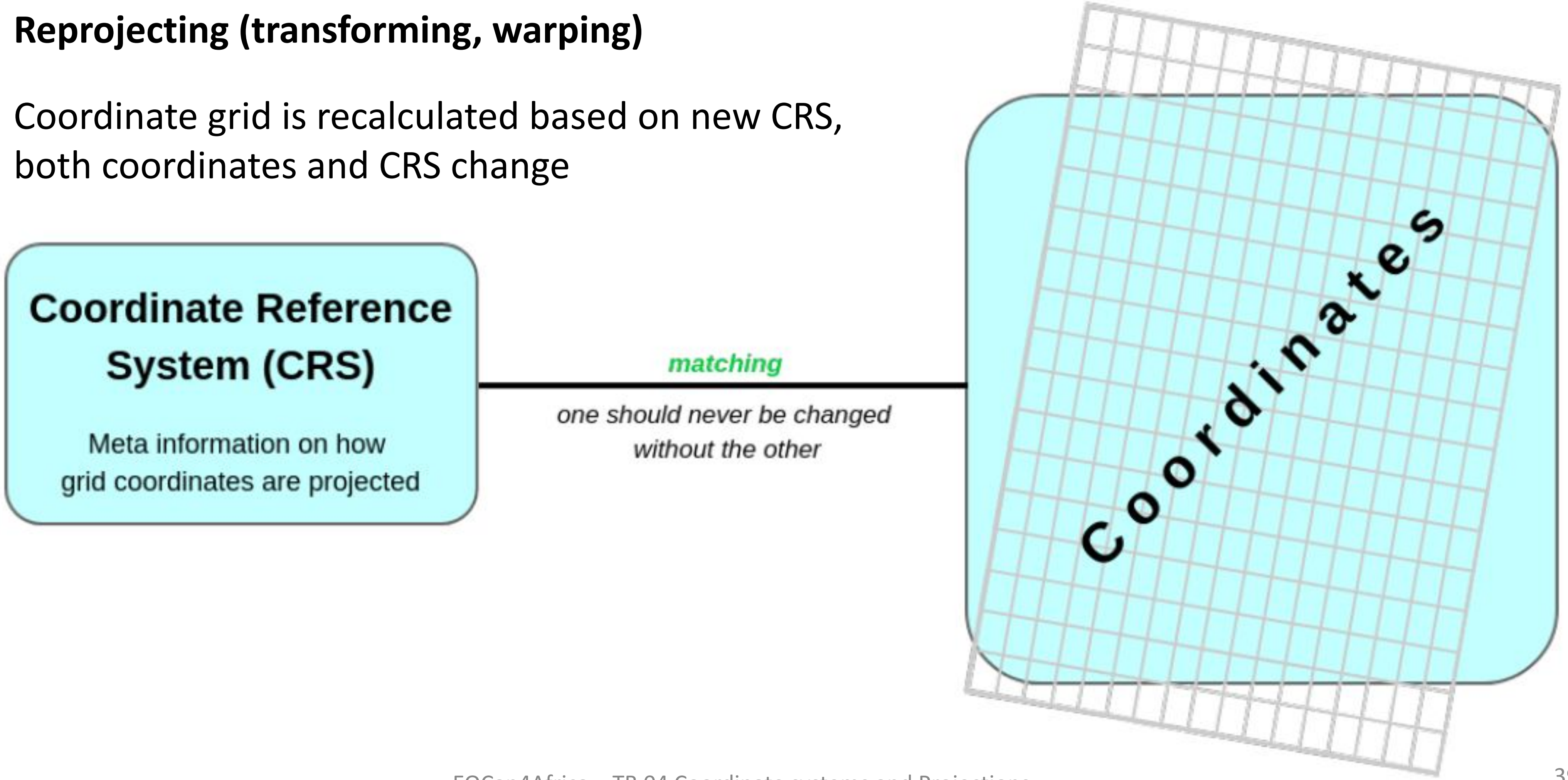
## Original coordinates and matching CRS



# CRS and coordinates

**Reprojecting (transforming, warping)**

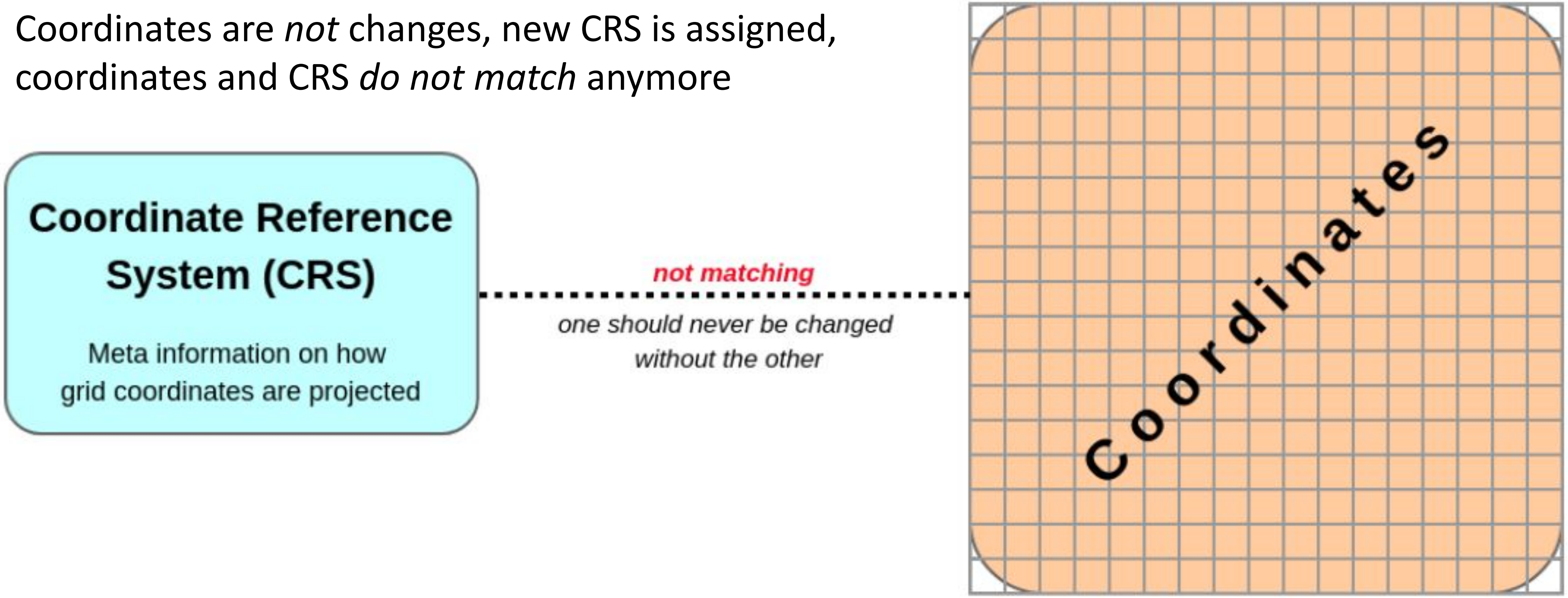
Coordinate grid is recalculated based on new CRS, both coordinates and CRS change



# 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 and colleagues**

insa.otte@uni-wuerzburg.de

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