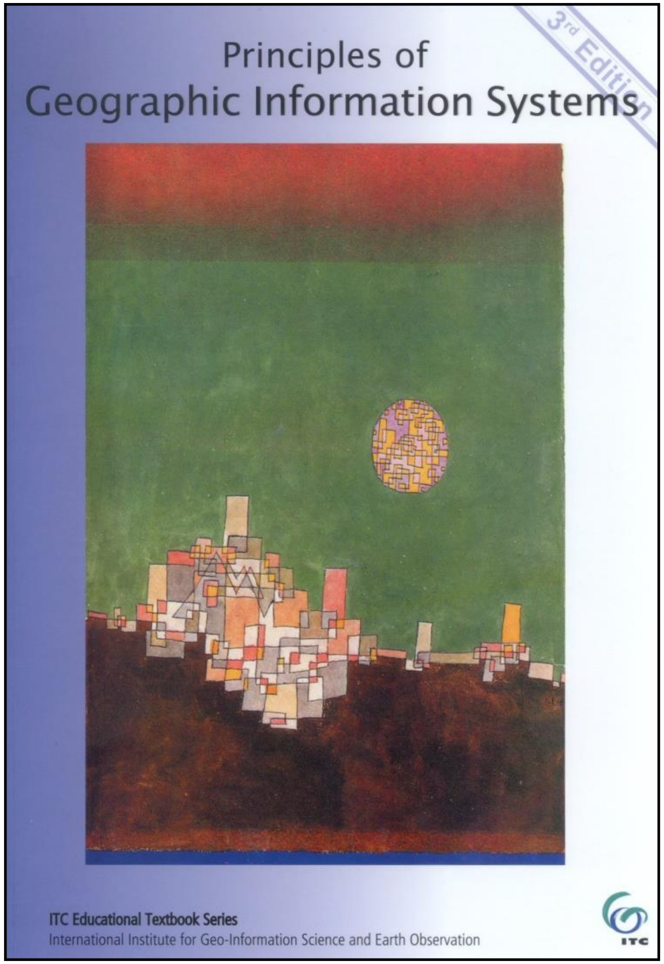
Spatial Referencing

Contents: lecture overview



1. A gentle introduction to GIS
2. Geographic information and Spatial data types
3. Data processing systems
4. Determining and mapping position
5. Data entry and preparation
6. Spatial data analysis
7. Data visualization

Why spatial referencing?

- Integration of data from different sources
- Combining national and global data sets
- Use of satellite positioning technology (e.g. GPS)
- ……

- GIS users need to understand basic concepts and terminology of spatial referencing

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The shape of the Earth - History

- an oyster
  (the Babylonians before 3000 B.C.)
- a circular disk
  (early antiquity; approximately 5 – 300 B.C. but this concept survived till the 19th century)
- a very round pear
  (Christopher Columbus in the last years of his life)
- a perfect ball → a sphere
  (Pythagoras in 6th century B.C.)
- an ellipsoid, flattened at the poles
  (Newton around the turn of the 17th and 18th centuries)

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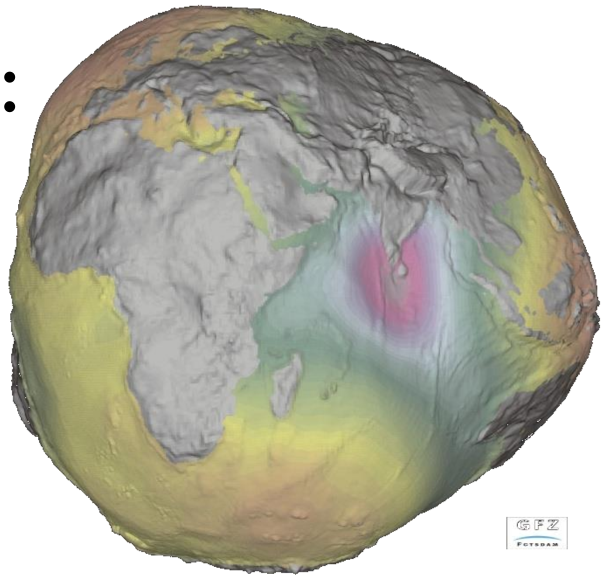
The shape of the Earth

- The surface of the Earth is irregular and continuously changing in shape due to irregularities in mass distribution inside the earth.
- The Earth has a “potato-like” shape
- The Earth as a Geoid
- It is the earth surface resulting if:
  - no topography would exist
  - oceans would cover the whole earth
  - the resulting water surface is only affected by gravity forces



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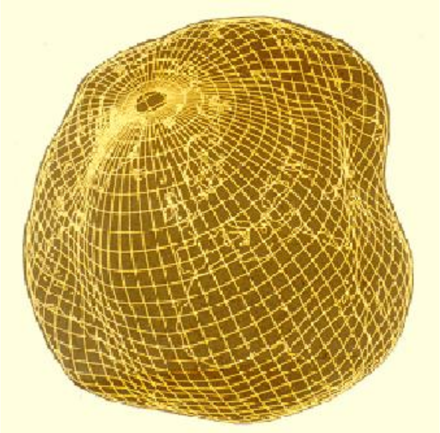
The Earth as a Geoid

- A geoid is "the physical figure of the earth"
- A geoid is an equipotential surface of the earth gravity field
- Every point on the geoid has the same zero height



- It is the earth surface resulting if:
  - no topography would exist
  - oceans would cover the whole earth
  - the resulting water surface is only affected by gravity forces

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The Geoid and the vertical datum

- A reference surface for **heights** (vertical datum) must be:
  - a surface of zero height
  - measurable (to be sensed with instruments)
  - level (i.e. horizontal)
- The geoid as reference surface for heights:
  - the geoid is approximately expressed by the surface of all the oceans of the Earth (Mean Sea Level)
  - every point on the geoid has the same zero height

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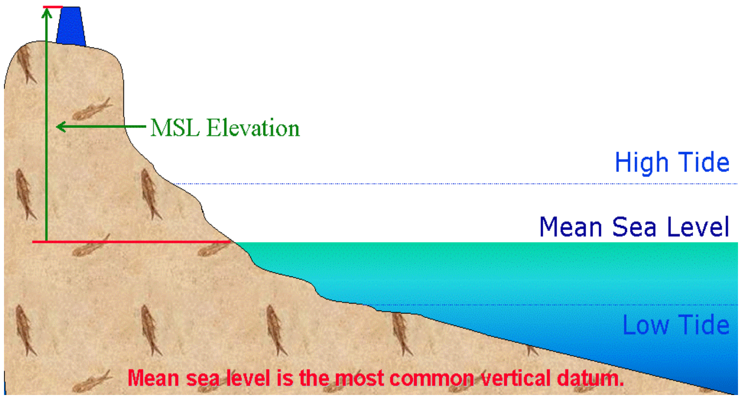
The Geoid and the vertical datum continued

- Mean Sea Level (MSL) is used as zero altitude
- the ocean's water level is registered at coastal locations over several years.
- Sea level at the measurement location is affected by:
  - tidal differences
  - ocean currents
  - winds
  - water temperature
  - salinity



Isle aux Morts (Station #666)
7 days Tidal Prediction
Reference : Chart Datum

Times and Heights for High and Low Tides

2006-02-02 (Thursday)		
Time	Height	
NST	(m)	(ft)
06:01	**0.4**	1.3
12:27	**1.7**	5.6
18:23	**0.5**	1.6

2006-02-03 (Friday)		
Time	Height	
NST	(m)	(ft)
00:42	**1.7**	5.6
06:51	**0.5**	1.6
13:13	**1.6**	5.2
19:07	**0.5**	1.6

2006-02-04 (Saturday)		
Time	Height	
NST	(m)	(ft)
01:35	**1.7**	5.6
07:40	**0.6**	2.0
13:57	**1.5**	4.9
19:51	**0.6**	2.0

2006-02-05 (Sunday)		
Time	Height	
NST	(m)	(ft)
02:31	**1.6**	5.2
08:35	**0.8**	2.6
14:45	**1.4**	4.6
20:44	**0.6**	2.0

2006-02-06 (Monday)		
Time	Height	
NST	(m)	(ft)
03:36	**1.5**	4.9
09:48	**0.9**	3.0
15:43	**1.3**	4.3
21:53	**0.7**	2.3

2006-02-07 (Tuesday)		
Time	Height	
NST	(m)	(ft)
04:53	**1.5**	4.9
11:25	**0.9**	3.0
16:55	**1.3**	4.3
23:14	**0.7**	2.3

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Chapter 4.2.2: p.97-98

Vertical datum

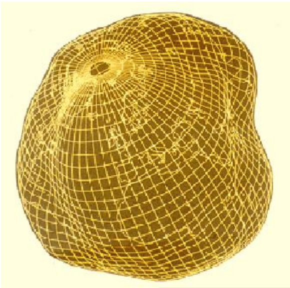
- Every country (or group of countries) has:
  - its own Mean Sea Level
  - its own local vertical datum
- Vertical datum in the Netherlands
  - Normaal Amsterdams Peil (N.A.P.)
  - Location: Amsterdam City Hall

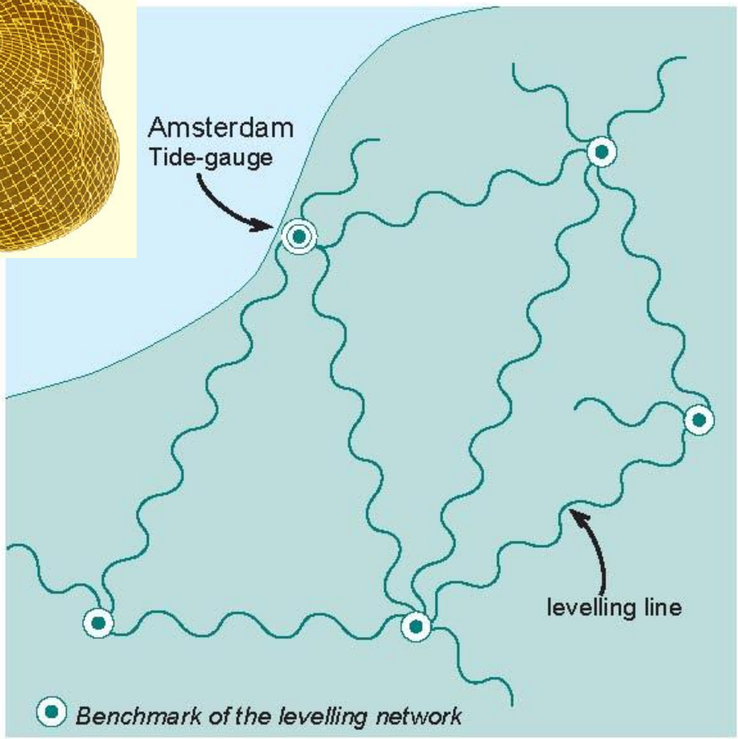
MSL Belgium is 2.34 m higher than MSL The Netherlands

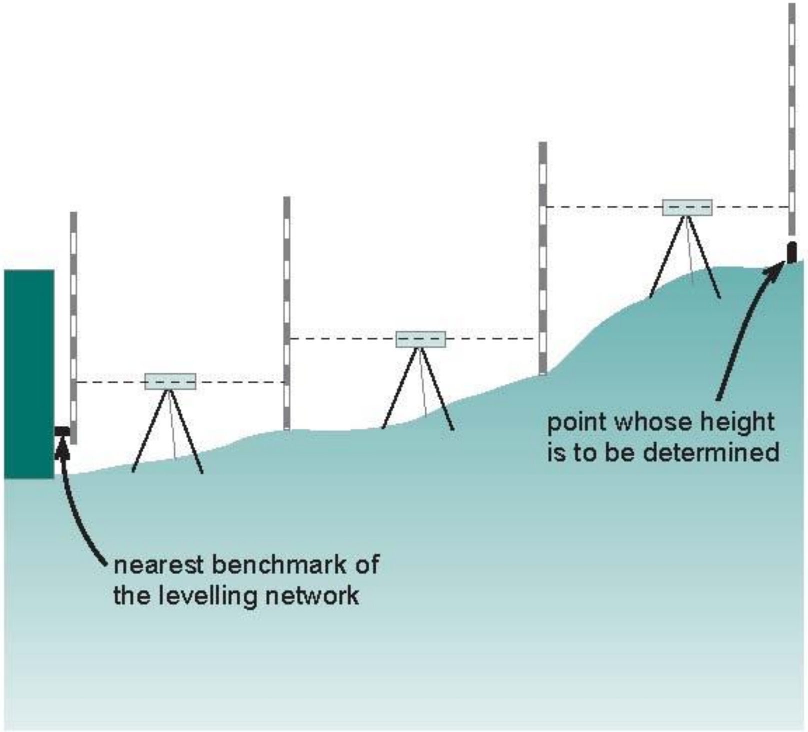
Chapter 4.2.2: p.97-98

Geodetic levelling

- the heights of points on the Earth can be measured using geodetic levelling techniques

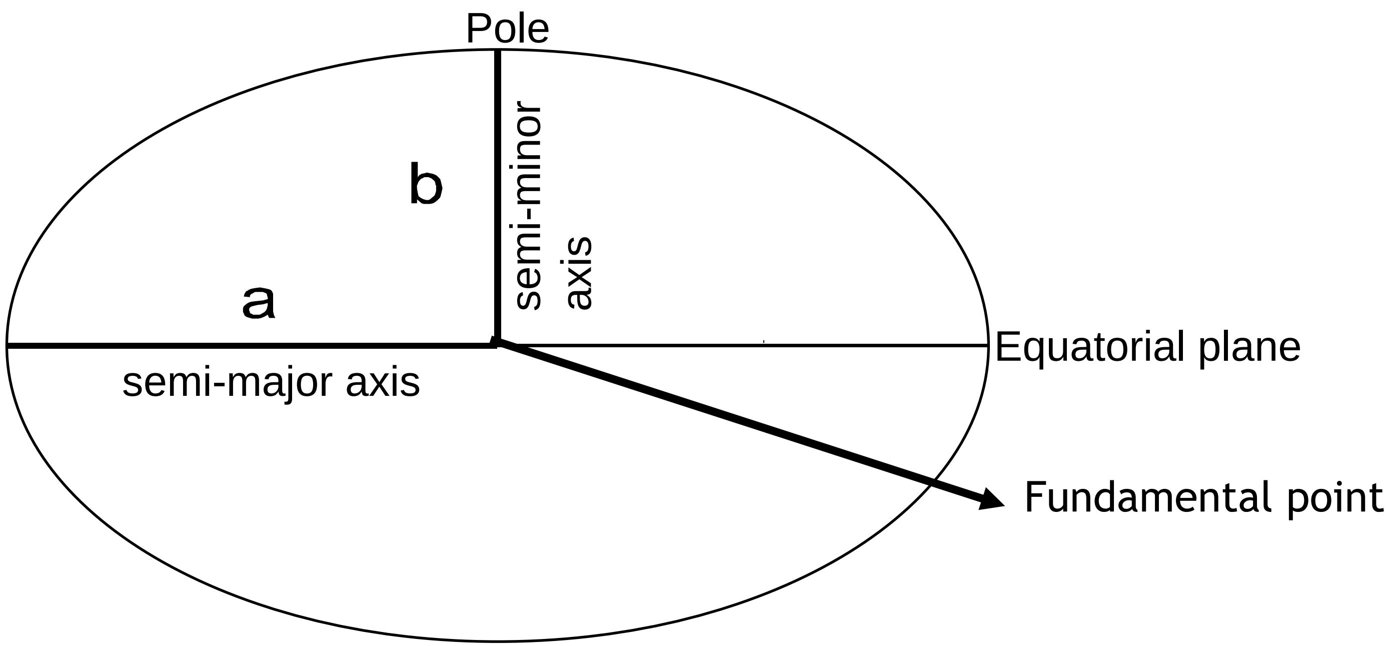






The ellipsoid and the horizontal datum

- A cross section of an ellipsoid, used to represent the Earth's surface

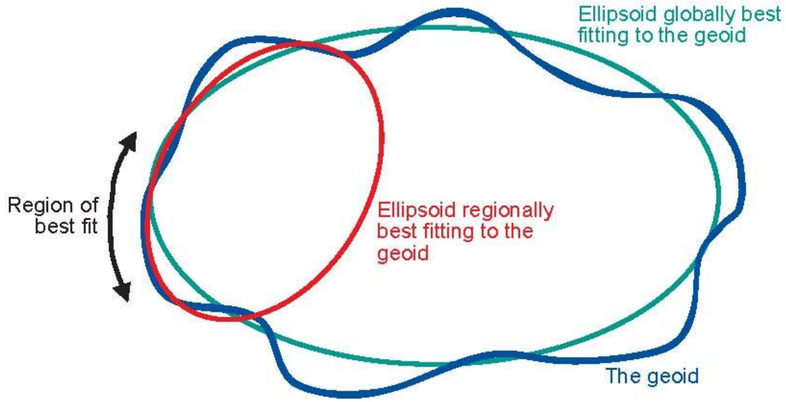


Flattening (f)
$f = (a-b)/a$

Eccentricity (e)
$e^2 = (1 - (b^2/a^2)) = (a^2-b^2) / a^2 = 2f - f^2$

Horizontal datum

- Countries establish a horizontal datum
  - an ellipsoid with a fixed position, so that the ellipsoid best fits the surface of the area of interest (the country)
  - topographic maps are produced relative to this horizontal (geodetic) datum



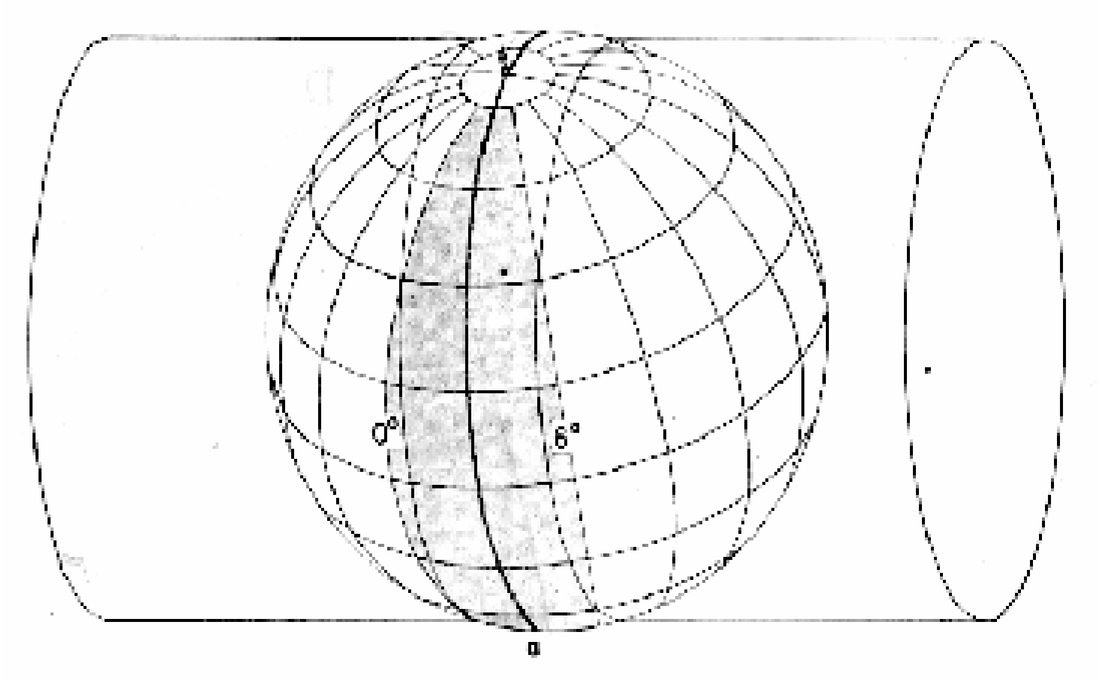
Coordinate Systems

- State Plane Coordinate System e.g. the USA

- **Universal Transverse Mercator Coordinate System**

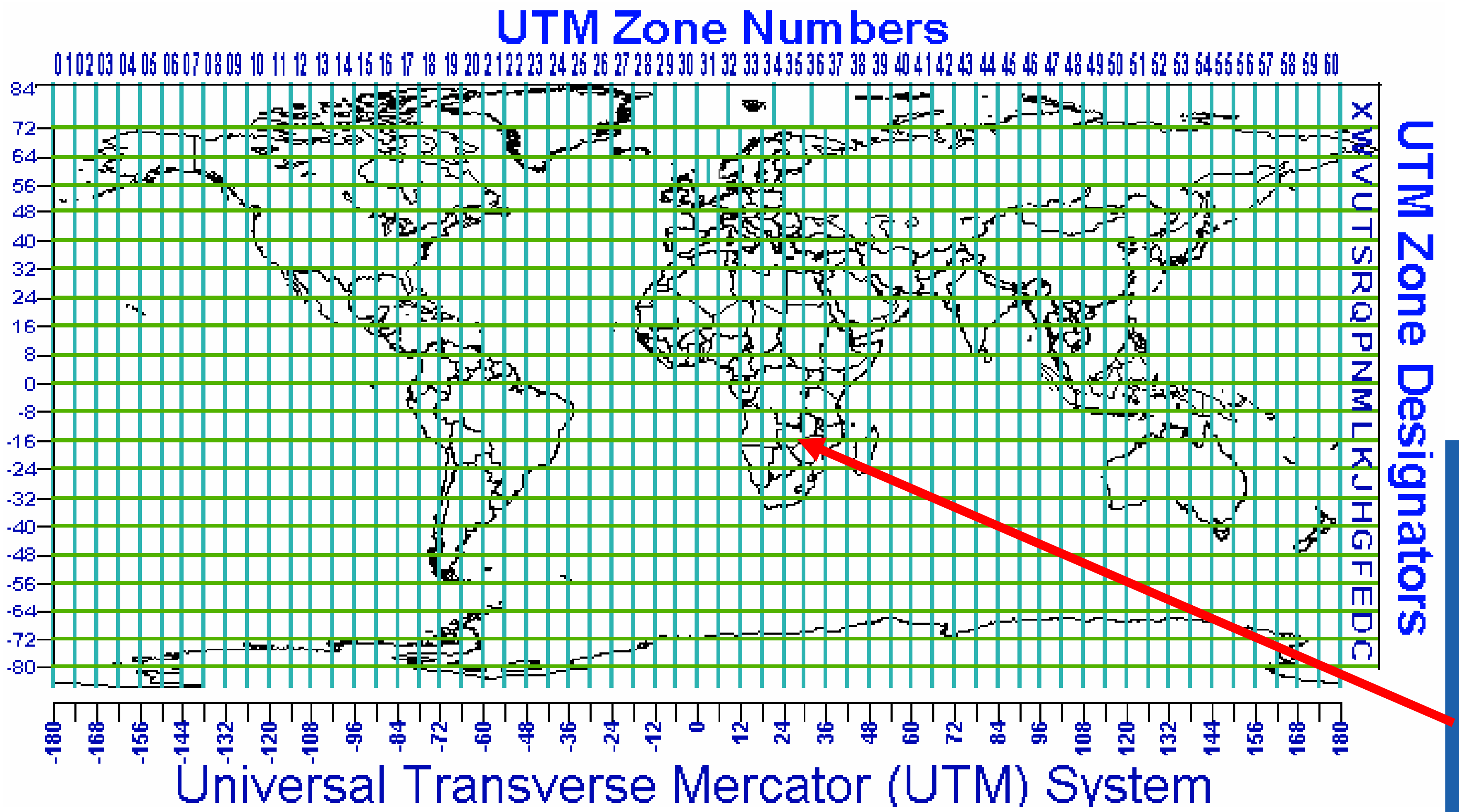
Universal Transverse Mercator (UTM) Projection

- A systematic Transverse Mercator projection
  – Covering the entire world
  – Used by USGS topographic maps since 1950s.
- A **conformal** projection using a cylindrical developable surface.
  – Area is distorted but not very serious within a zone.
  – Secant to the spheroid.



UTM Zones Around World

Each zone has 6°, 60 zones around world. First zone is180°W - 174°W; central meridian is 177°W.



UTM Zone Details

Each Zone is 6 degrees wide
(84ºN to 80ºS).

- Origin at the Equator, 500,000m west of the zone central Meridian
- Coordinates discontinuous across zone boundaries
- Coordinates are always positive (10,000,000 offset for South Zones)

Map Projections

- **Projections convert geographic coordinates to 2D plane coordinates.**

- All projections have distortion
  - Some properties are preserved at the expense of others
  - Distortion varies across a map

- There are standard coordinate systems
  - SPCS
  - UTM

Units for Latitudes and Longitudes

- Degrees
  - Degrees, Minutes, and Seconds (DMS) e.g. 35° 46′ 20″
  - Decimal Degrees (DD) e.g 35.7722°
  - DD DMS: Decimal Degrees = Degrees + Minutes/60 + Seconds/3600

    e.g. 35 + 46/60 + 20/3600 = 35.7722°

- Radians (360° ~ 2π)
  - Decimal degrees (DD) radians

    1° = π / 180 = 0.01744 radians

    1 radian = 180 / π = 57.32°

The ellipsoid and the horizontal datum

- A reference surface for **locations** (horizontal datum)
  - must be a mathematical reference surface to “project” coordinates in the plane, compute positions distances, directions, etc.
  - The geoid is NOT suitable as a reference surface for the determination of locations
  - The ellipsoid is the most convenient geometric reference for measuring locations

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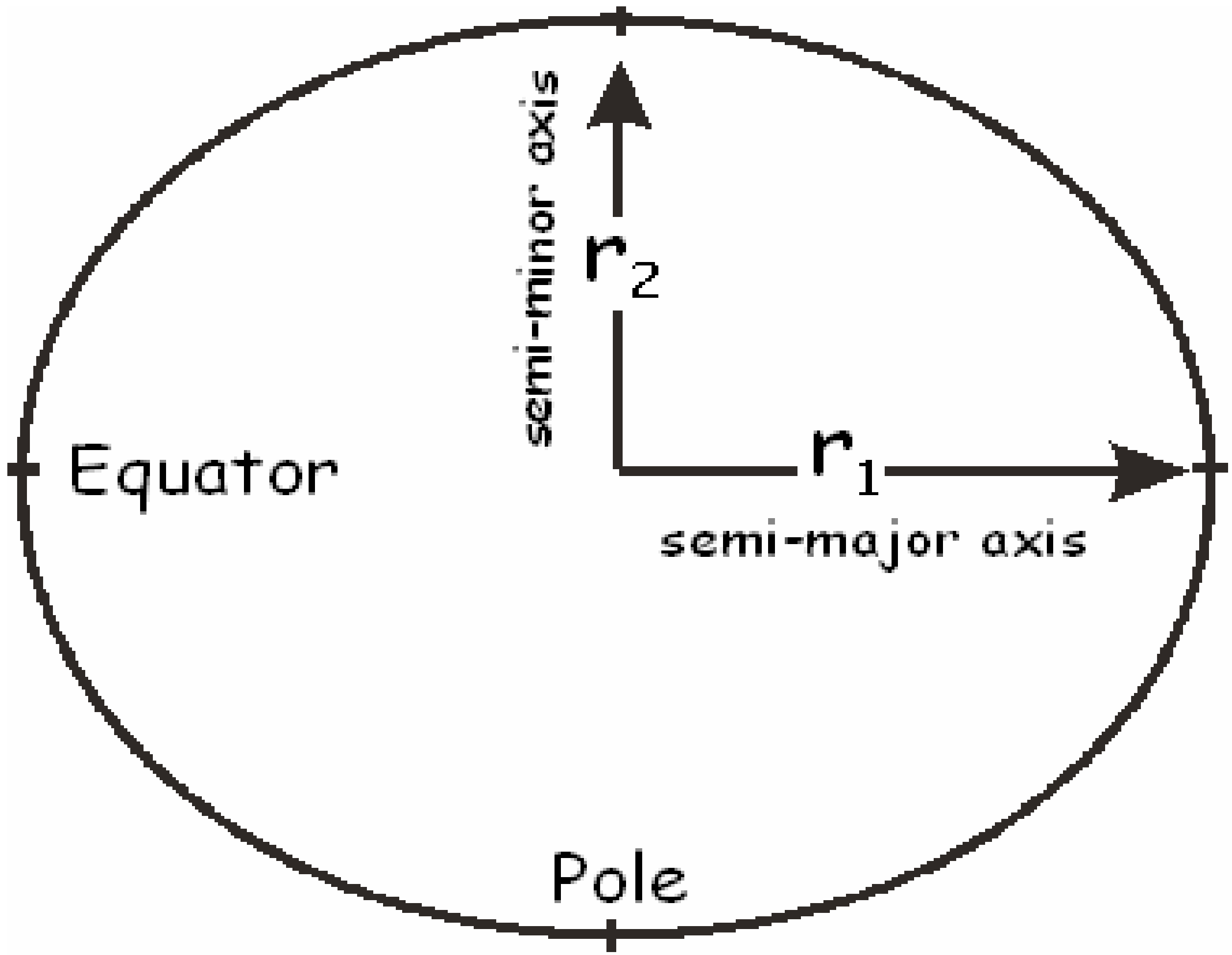
An Ellipsoid Model

- Two radii:
  - r1, along semi-major (through Equator)
  - r2, along semi-minor (through poles)
  - Flattening factor

$$f = \frac{r_1 - r_2}{r_1}$$



The Best Ellipsoid?

- No one could agree on the right size
  - What are the best estimates of r1 and r2?
  - Different surveys came up with different estimates

- Result
  - Different countries adopted different “standard” ellipsoids
  - In USA, same county adopted different ellipsoids at different times.

Ellipsoidal Models of the Earth

Selected Reference Ellipsoids

Ellipse	Semi-Major Axis (meters)	1/Flattening
Airy 1830	6377563.396	299.3249646
Bessel 1841	6377397.155	299.1528128
Clarke 1866	6378206.4	294.9786982
Clarke 1880	6378249.145	293.465
Everest 1830	6377276.345	300.8017
Fischer 1960 (Mercury)	6378166.0	298.3
Fischer 1968	6378150.0	298.3
G R S 1967	6378160.0	298.247167427
G R S 1975	6378140.0	298.257
G R S 1980	6378137.0	298.257222101
Hough 1956	6378270.0	297.0
International	6378388.0	297.0
Krassovsky 1940	6378245.0	298.3
South American 1969	6378160.0	298.25
WGS 60	6378165.0	298.3
WGS 66	6378145.0	298.25
WGS 72	6378135.0	298.26
WGS 84	6378137.0	298.257223563

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Many reference ellipsoids are in use by different nations and agencies at different times.

The Creation of a Datum

- **A network of precisely-measured control points based on the selected ellipsoid.**
- Control points define how the underlying ellipsoid is aligned to the Earth.
- **Control points are measured relative to other control points & marked as monuments.**
- e.g. in USA The National Geodetic Survey (NGS) maintains approximately 270,000 first- order horizontal control points.
- **Control networks may then be extended from first-order control points.**

Datum

- **A datum:**

– uses an ellipsoid to approximate the shape and size of the Earth

– defines how the sphere or ellipsoid is ***aligned*** to the Earth.

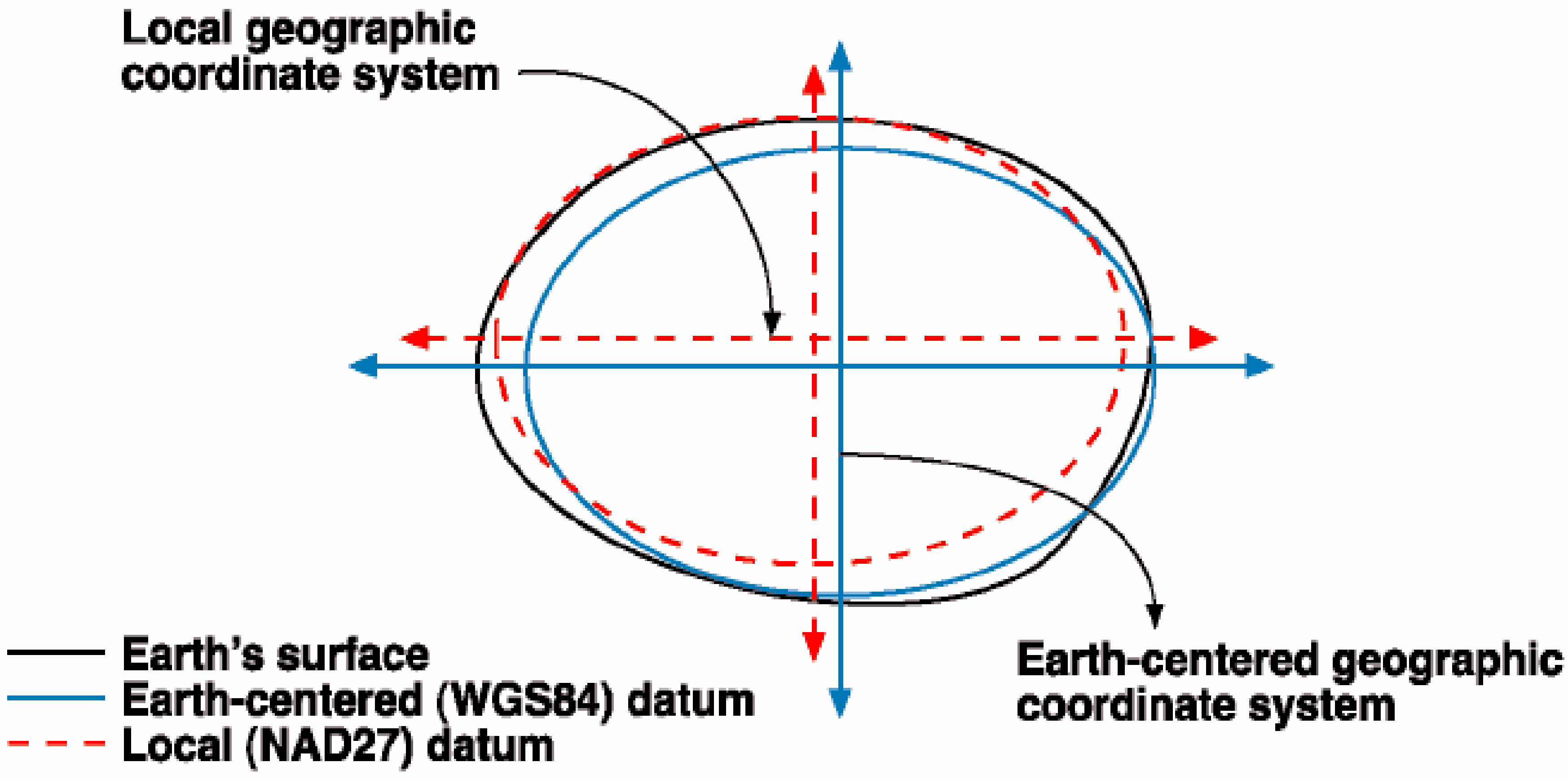
- The same sphere or ellipsoid can be aligned to the Earth differently.

- For practical use, a datum is determined by a set of control points

– Precisely known coordinates on the selected ellipsoid

Local (regional) and Global Datums

• fitted to the Earth overall or fitted to the Earth for a certain region.
• NAD27 and WGS84



Selected Datums

Selected Geodetic Datums and WGS-84 Shift Parameters				
Datum	Ellipsoid	DX	DY	DZ
Adindan	Clarke 1880	-162	-12	206
Arc1950	Clarke 1880	-143	-90	-294
Arc1960	Clarke 1880	-160	-8	-300
Australian Geodetic 1966	Austrilian National	-133	-48	148
Australian Geodetic 1984	Australian National	-134	-48	149
Camp Area Astro	International	-104	-129	239
Cape	Clarke 1880	-136	-108	-292
European Datum 1950	International	-87	-98	-121
European Datum 1979	International	-86	-98	-119
Geodetic Datum 1949	International	84	-22	209
Hong Kong 1963	International	-156	-271	-189
Hu-Tzu-Shan	International	-634	-549	-201
Indian	Everest	289	734	257
North American Datum 1927	Clarke 1866	-8	160	176
North American Datum 1983	GRS 80	0	0	0
Oman	Clarke 1880	-346	-1	224
Ordinance Survey 1936	Airy	375	-111	431
Bulkovo 1942	Krassovsky 1942	27	-135	-89
Provisional S American 1956	International	-288	175	-376
South American 1969	S American 1969	-57	1	-41
Tokyo	Bessel 1841	-128	481	664
World Geodetic System 1972	WGS 72	0	0	-4.5
World Geodetic System 1984	WGS 84	0	0	0

Survey Benchmarks

Height Measurement

- What does it mean to say that Mt. Kilimanjaro, the highest peak in Tanzania, has a height of 14,433 m?

- Where is this measured from?
  - The center of the Earth
  - The reference ellipsoid
  - Somewhere else

- The *zero surface to which elevations are referred to* is called a **vertical datum**

Geoid

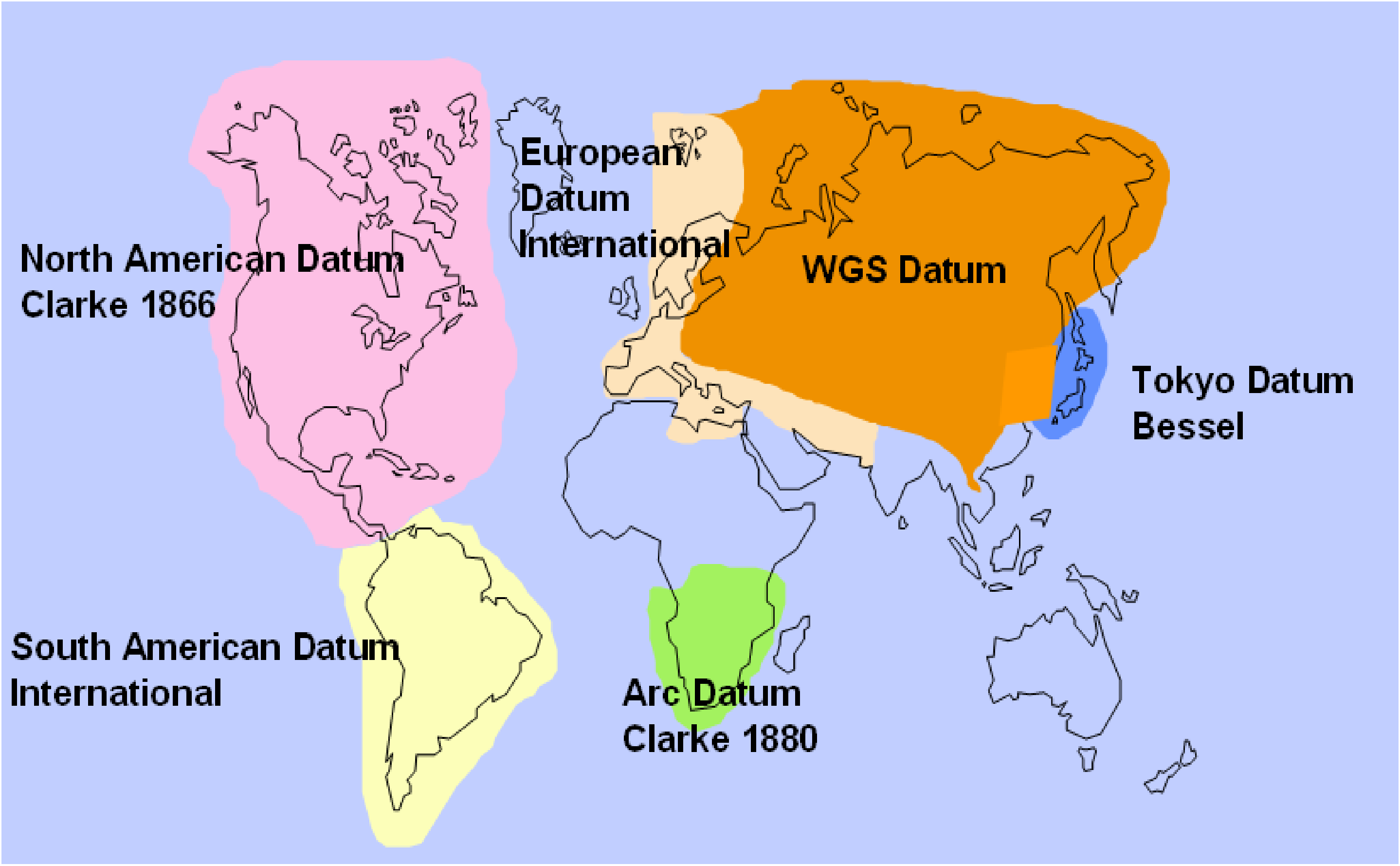
- **Traditionally, the mean sea level is used as the definition of zero elevation.**
  – Measurable
  – Available worldwide
- A geoid is an equipotential surface of the Earth's gravity field which best fits global mean sea level (NGS definition)
- Maximum difference between geoid and MSL is about 1 meter.
- **Local variations in gravity, caused by the irregularities in the density of the Earth’s crust and mantle make the surface irregular.**
- A measured surface (not mathematically defined)

– surface instruments (gravimeters) and measurements of satellites

Components of a Geographic Coordinate System (GCS)

A geographic coordinate system consists of
Datum (Spheroid, Alignments), Unit of Measure (DMS or DD) and Prime Meridian

Horizontal datums



Commonly used ellipsoids

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)

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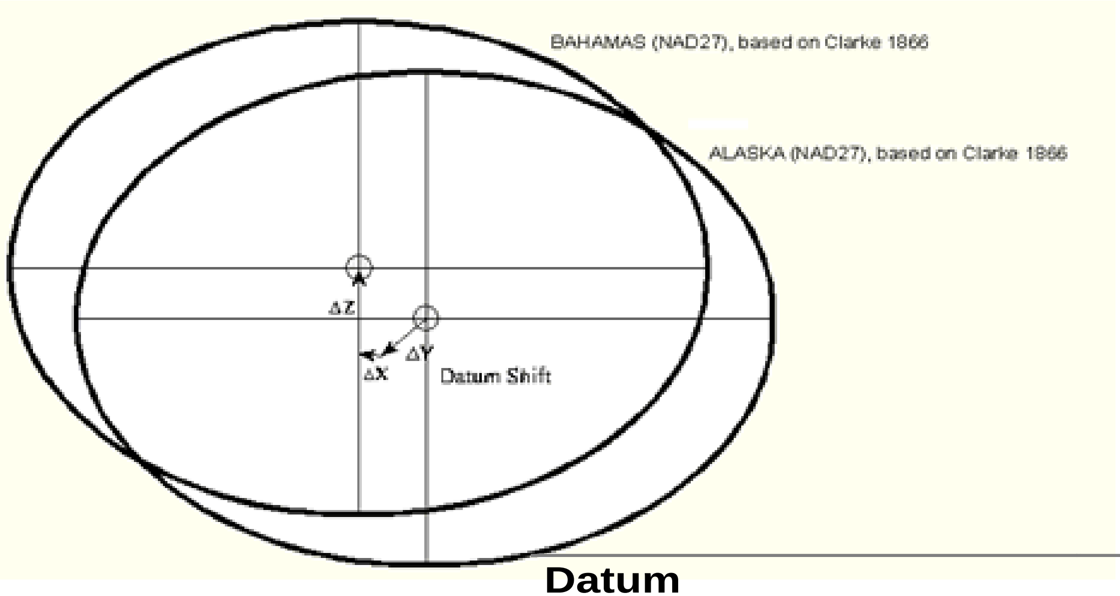
Different datums, same ellipsoid



Datum	Ellipsoid	Datum shift (m) (Δx, Δy, Δz)
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

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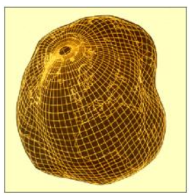
The shape of the Earth: Summary



Sphere	Only a very rough approximation	Used as baseline for x/y positioning and for projections
Ellipsoid	Mathematical approximation of earth shape. Ca 1/297 flattening in N-S axes	Used as baseline for x/y positioning and for projections
Geoid	"Real" shape of Earth except for the topography. Truly horizontal surface (perpendicular to local gravity) but hard to describe mathematically	Used as baseline for z measurements
Topography	The extra z measured above / below the local horizontal datum	Remember: Levelling follows shape of Geoid not Ellipsoid!

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Map projections

- **Formal definition**
  a map projection is a mathematically described technique of how to represent the curved planet's surface on a flat map
- Two reference surfaces are applied:
  - Ellipsoid for large-scale mapping
    (small area, much detail, e.g. 1:50,000)
  - Sphere for small-scale mapping
    (large area, less detail, e.g. 1:1,000,000)

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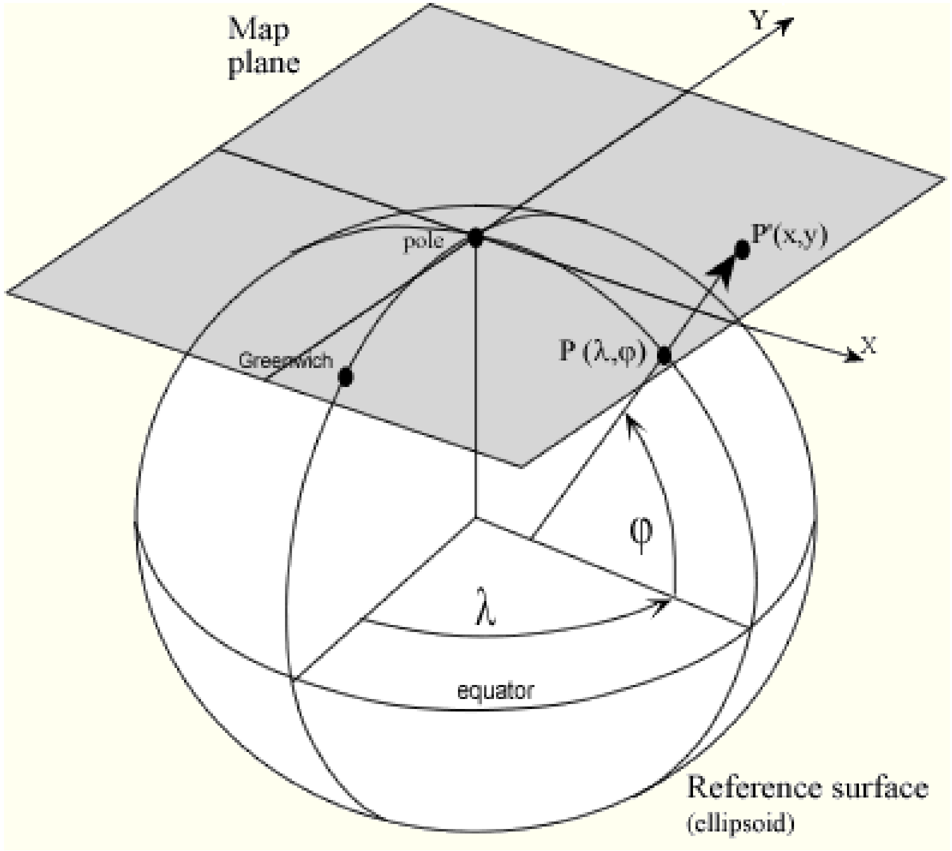
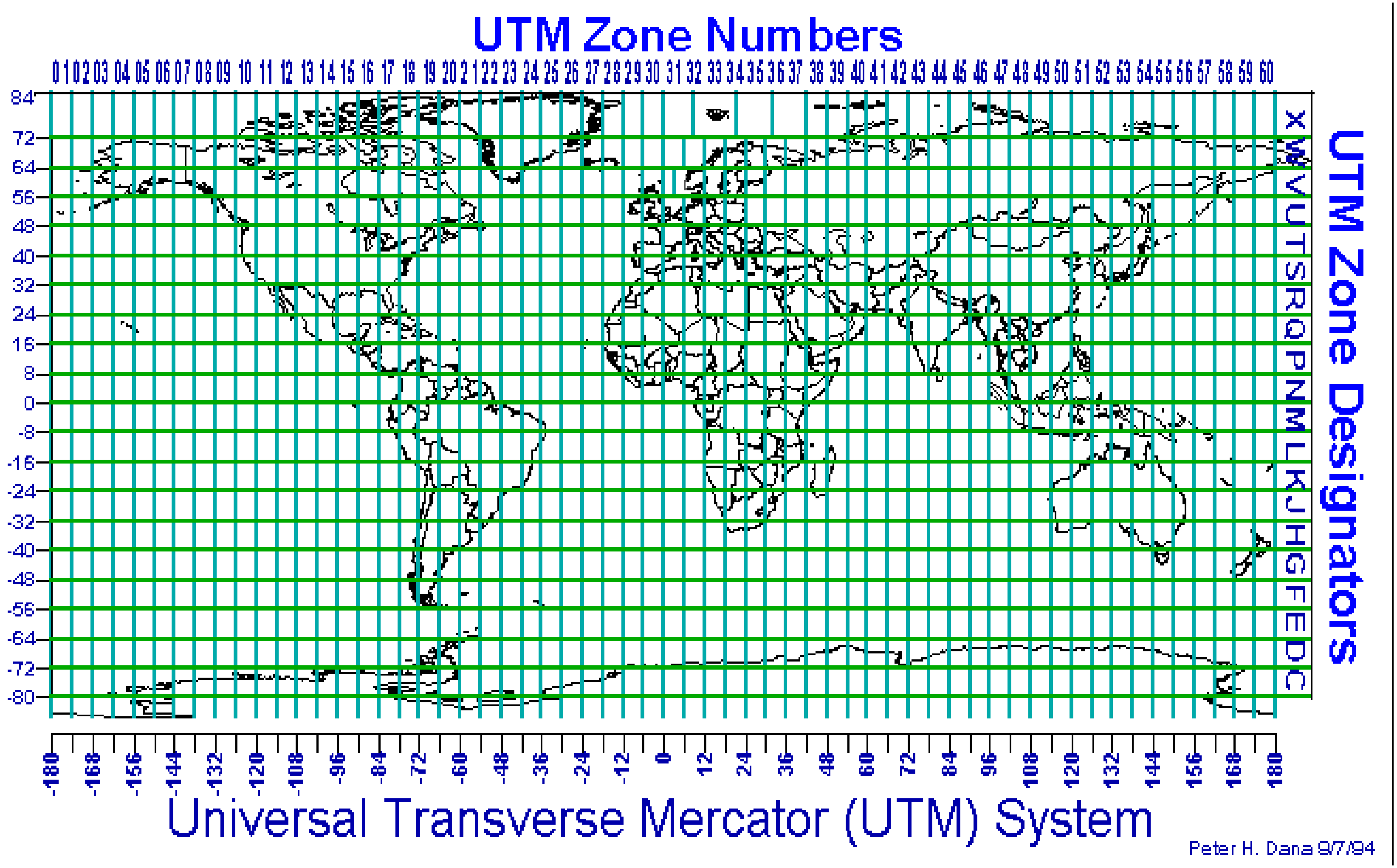
Map projection: principle



Classification of map projections

- Based on inventor
  - Mercator
  - Lambert
  - …..

UTM Zones


UTM Zone Numbers
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
84 72 64 56 48 40 32 24 16 8 0 -8 -16 -24 -32 -40 -48 -56 -64 -72 -80
X W V U T S R Q P N M L K J H G F E D C
UTM Zone Designators
-180 -168 -156 -144 -132 -120 -108 -96 -84 -72 -60 -48 -36 -24 -12 0 12 24 36 48 60 72 84 96 108 120 132 144 156 168 180
Universal Transverse Mercator (UTM) System
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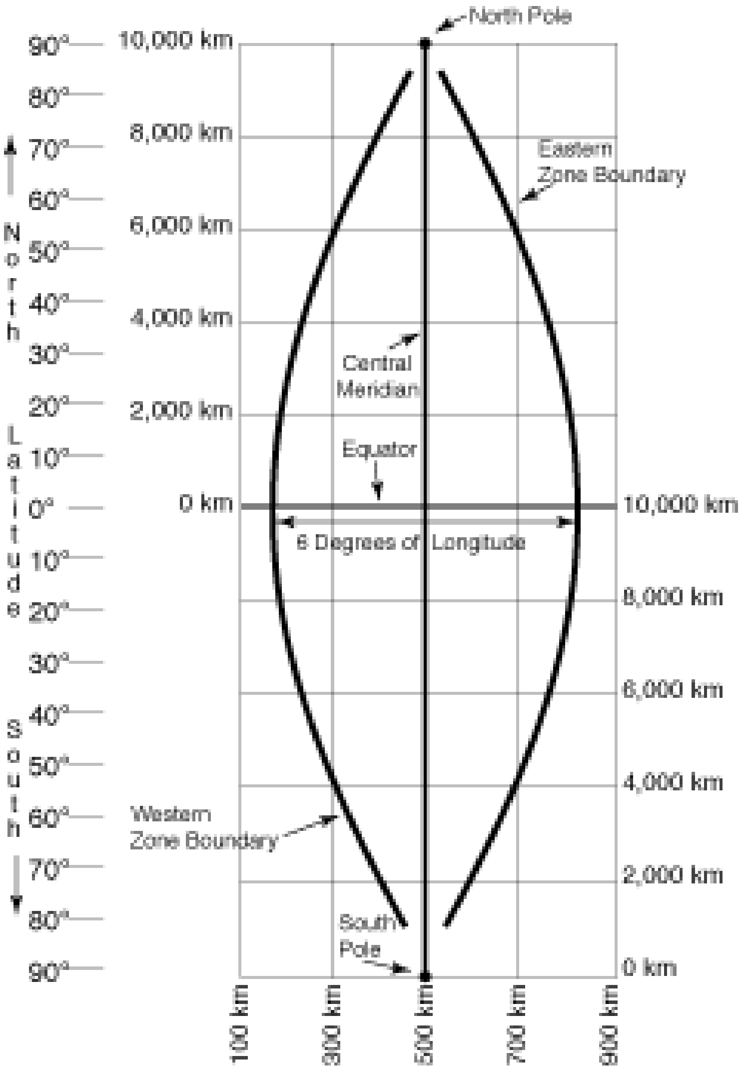
A UTM Zone



Transverse cylindrical projection: the cylinder is tangent along meridians

60 zones of 6 degrees

Zone 1 starts at longitude 180° (in the Pacific Ocean)

Polar zones are separately mapped

X coordinates – six digits (usually)

Y coordinates – seven digits (usually)

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UTM Zone Coordinates

- **Eastings are measured from the central meridian**
  - With **False Easting** to ensure positive values
- **Northings are measured from the equator**
  - With a **False Northing** for positions South of the equator
- **False origin**
  - False Easting = 500,000 meters
  - False Northing:
    - 0 meters for areas North of the Equator
    - 10,000,000 meters for areas South of the Equator

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Choosing a Map Projection

- The selection of a Map projection has to be made on the basis of:
  - Purpose of the map
  - Shape and size of the area
  - Position of the area

In conclusion

- What is spatial referencing ?
  - selecting a vertical datum
  - selecting an appropriate horizontal datum
    - includes ellipsoid definition
  - selecting an appropriate map projection

- References
  - http://kartoweb.itc.nl/geometrics

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