Ekonomická fakulta
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Geographic Information Systems 1
Lecture 8: Geographical location - coordinate systems

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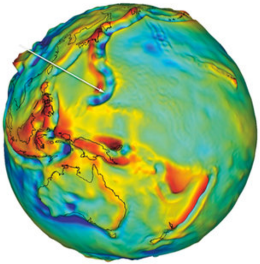
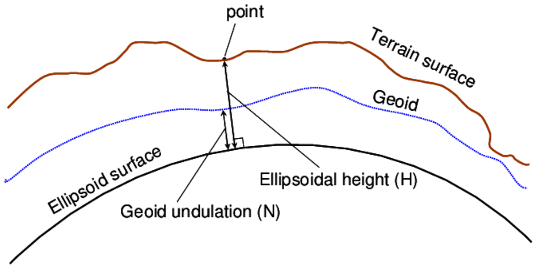
The evolution of the planet Earth has created a relatively rugged and rugged surface - various morphological formations (mountain ridges, valleys, ...).
Every point on Earth can be the subject of geodetic exploration. We therefore need some form of simplification that would lead to a universal mapping of the real surface of the Earth on the surface of a map (on paper).



ideal surface = equilibrium surface of the gravitational force field = **geoid** = more precisely: a zero level equipotential surface, which is at every point perpendicular to the direction of gravity.

area describing the terrestrial relief = **topographic area**
While the geoid surface is in some sense ideal, neither the topographic surface nor the geoid can be mathematically expressed and described.

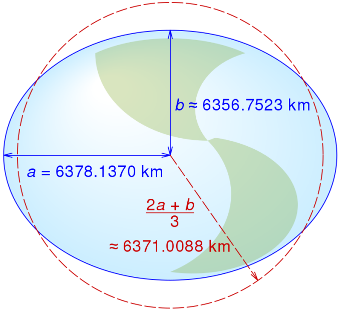


Therefore, another approximation is introduced: the **rotating ellipsoid** = the so-called biaxial ellipsoid, which is formed by the rotation of the ellipse around the minor semi-axis - a mathematically defined body whose surface adheres as closely as possible to the geoid. It can be expressed by the equation:

$$\frac{x^2+y^2}{a^2}+\frac{z^2}{b^2}=1.$$

two ways of approximating the Earth's surface and the resulting ellipsoid types associated with them:

- **earth ellipsoid** - formed by approximating the geoid, the centre is identical to the centre of mass of the Earth (geocentre), the minor axis is identical to the centre of rotation;
- **reference ellipsoid** - created by approximating a part of the geoid, the centre is not identical to the centre of the Earth, it approximates the selected area better than the Earth ellipsoid, the views defined on the rotation ellipsoid show less distortion than the views defined on the Earth ellipsoid.



GIS related fields - rotating ellipsoid referred to as reference (surrogate) ellipsoid

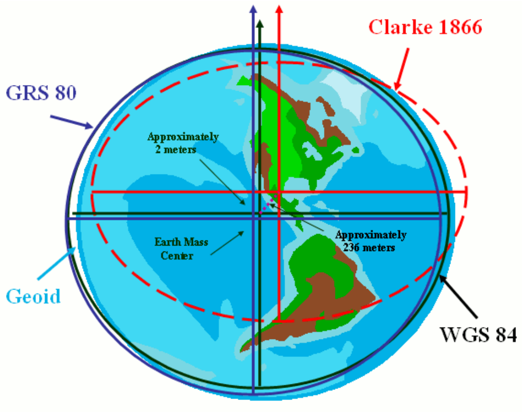
Different choices of the ellipsoid replace the geoid with different accuracy (truthfulness) $\Leftarrow$ at different places of the geoid the ellipsoid adjoins differently (the distance of the geoid area from the ellipsoid changes).

English literature: the choice of an alternate ellipsoid for a particular application is called **datum**.

WGS-84 = global ellipsoid - developed over a long period of time and stabilized only in 1984, not suitable for national geodesy purposes.

Parameters of the most famous ellipsoids:

Elipsoid	a [m]	b[m]	Typ
Besselův	6377397,1550	6356078,9633	RE
Hayfordův	6378388,0000	6356911,9461	RE
Krasovského	6378245,0000	6356863,0188	RE
WGS 84	6378137,0000	6356752,3142	ZE
Clarkův (1880)	6378249,1450	6356514,8696	RE
GRS 80	6378137,0000	6356752.3141	ZE
NAD 1927	6378206,4000	6356583,8000	RE
IAG 1967	6378160,0000	6356774,5160	ZE



Reference ellipsoids used in the Czech Republic:

- **Bessel** ellipsoid - since 1841,
- **Krasovsky** ellipsoid - introduced in Czechoslovakia in 1953.

Elipsoid	a (m)	b (m)	rok určení	referenční systém
Besselův	6 377 397	6 356 079	1841	S-JTSK
Krasovskeho	6 378 245	6 356 863	1940	S-42/83
WGS-84	6 378 137	6 356 752	1984	WGS-84, ETRS

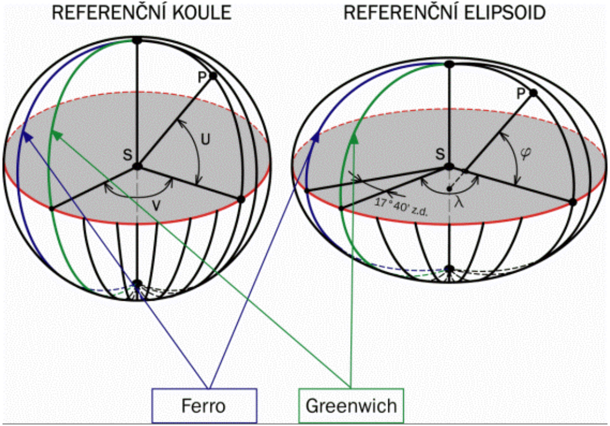
The reference ellipsoid can then be replaced by a simpler solid - **reference sphere** - simpler mathematical definition - has larger deviations from the geoid than the ellipsoid - the radius R can be chosen in different ways and has the following properties:

- constant curvature,
- it is easier to perform calculations on it,
- it is suitable for small and medium scale maps (not state map work).

The reference sphere can be replaced:

- ellipsoid **local** (area 300 x 300 km) - precise calculations on a small area (differences can be neglected),
- ellipsoid **globally** - less accurate calculations over the entire surface of the Earth - use in geographic cartography.

The cartographic distortions when replacing a geoid with a sphere are 2 orders of magnitude (100x) greater than when replacing a geoid with an ellipsoid.



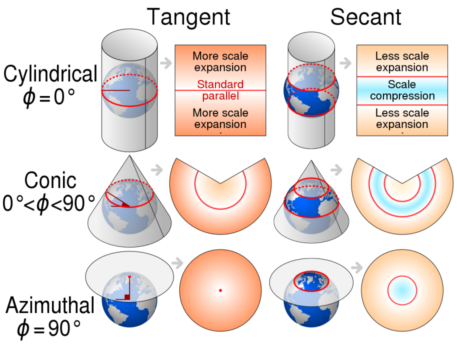
When replacing an ellipsoid by a sphere on a small area, we can choose its radius R in the following ways:

- $R = a$,
- $R = b$,
- $R = \sqrt{MN}$ is the mean radius of curvature.

Replacing the ellipsoid globally can be done in the following ways:

- the sphere will have the same volume as the ellipsoid, i.e. $R = \sqrt[3]{a^2 b}$;
- the sphere will have the same surface as the ellipsoid, i.e. $R = b\sqrt{1 + \frac{2}{3}e^2 + \frac{3}{5}e^4 + \frac{4}{7}e^6 \ldots}$;
- the diameter of the sphere will be expressed as the arithmetic mean of the semi-axes, i.e. $R = \frac{2a+b}{3}$.

- unambiguous definition of topology and geometry using the coordinate system,
- procedure: geoid → reference ellipsoid → geographical coordinates → cartographic view → map.



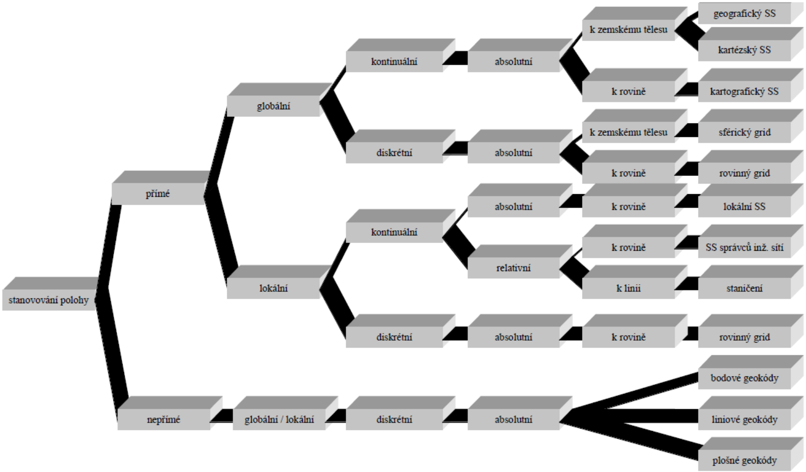
When creating a two-dimensional map, it is then necessary to convert the image from a three-dimensional template (reference ellipsoid or reference sphere) into a plane.

projection surface = area on which we display objects from the reference area - types:

- cylindrical,
- conic,
- azimuthal.

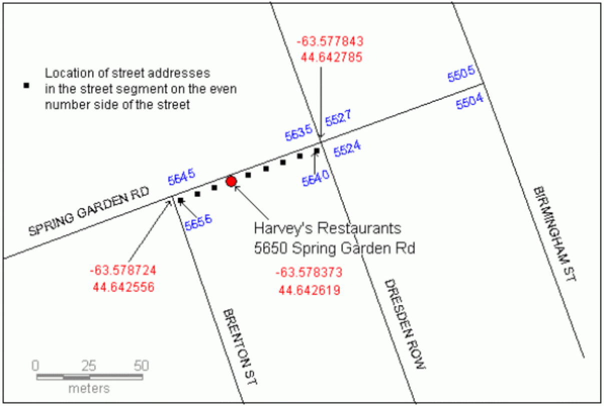
Can be displayed on more than one surface (**polyconic projections**).

Before we can work with geofeatures, we need to unambiguously define their position in space.
spatial reference systems:



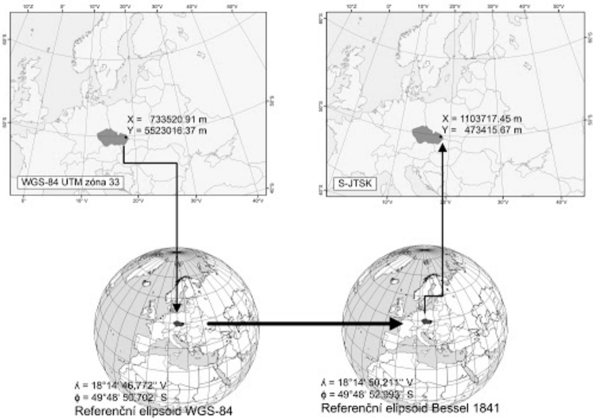
There are basically two ways to determine the position:

- directly using coordinate systems (**georeferencing**),
- indirectly using geocodes (**geocoding**).



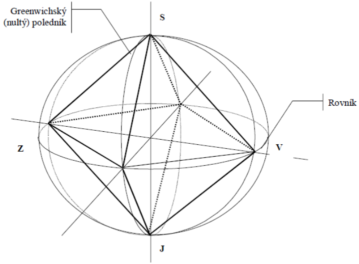
coordinate systems:

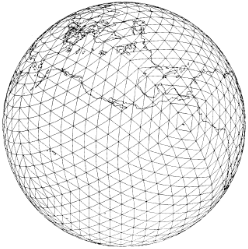
- **global**,
- **local**.

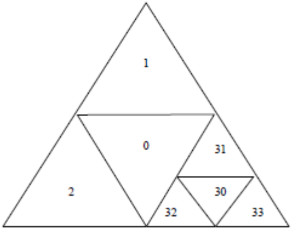


... Earth, whole states or large parts of states:

- **continuous** - they are based on continuous position measurements, without jumping coordinate changes and interruptions:
  - absolute,
  - relative;
- **discrete** - e.g. **spherical grid** (derived from an octahedron inscribed in the globe, whose triangular sides are successively divided into smaller and smaller triangles, with the newly generated vertices adjacent to the Earth's surface).





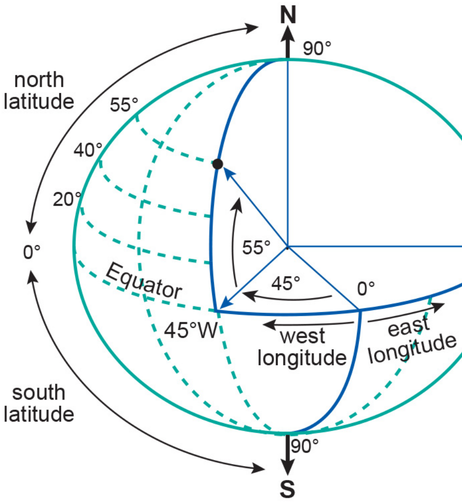


... relative to the earth's body:

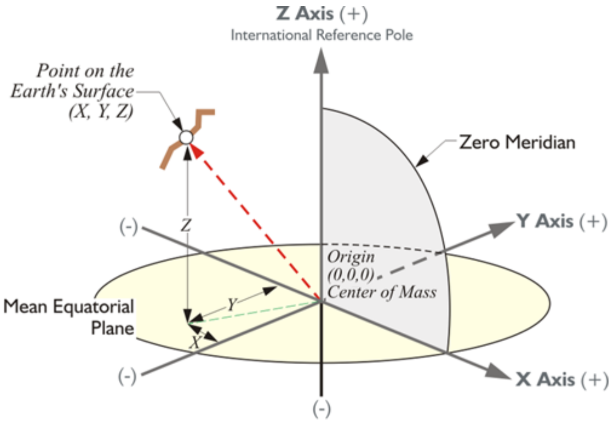
- **Geographic coordinate system** - latitude φ, (latitude) and longitude λ (longitude), geographical coordinates are sometimes supplemented by altitude h, given in meters;
- **Cartesian coordinate system** - beginning at the centre of the Earth, gives the position of a point using a triplet of coordinates $[x, y, z]$. The x and y axes lie in the plane of the equator, the x axis passes through the intersection of the zero meridian and the equator, the z axis is perpendicular to them and usually identical to the Earth's axis of rotation.

While in the case of the geographic coordinate system, the position is defined by only two coordinates and it is automatically assumed that the described point lies on the surface of the Earth, in the case of the Cartesian coordinate system the position is described by three coordinates.

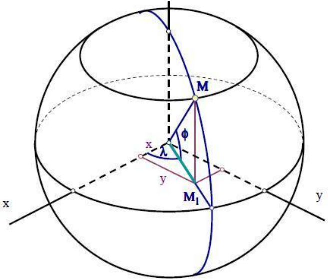
Geographic coordinate system:



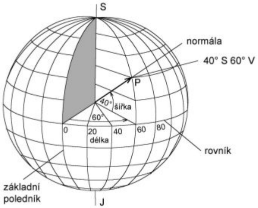
Cartesian coordinate system:



conversion of geographic - cartographic coordinates:



$$x = R \cdot \cos\phi \cdot \cos\lambda$$
$$y = R \cdot \cos\phi \cdot \sin\lambda$$
$$z = R \cdot \sin\phi;$$
$$\lambda \in \langle 0, 2\pi); \quad \phi \in \left\langle -\frac{\pi}{2}, \frac{\pi}{2} \right\rangle$$



... there are many - they are related to cartographic techniques: if we want to represent a certain large part of the Earth's surface (where curvature can no longer be neglected) on a flat map, we have to perform the following transformations:

1. reducing the scale so that the displayed area fits on the desired size sheet of paper,
2. to project a curved surface onto a plane in a systematic way. This projection is called cartographic mapping and is essentially a systematic transformation of the geographic coordinates (φ, λ) into the corresponding planar coordinates (x, y) of the map. Mathematically, this transformation can be written as follows:

$$\begin{aligned} x &= f_1(\varphi, \lambda) \\ y &= f_2(\varphi, \lambda) \end{aligned}$$

and indicate schematically:

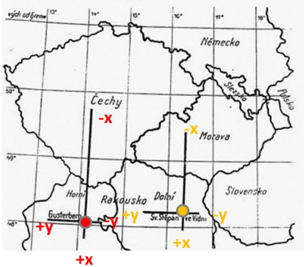
$$(\varphi, \lambda) \rightarrow (x, y)$$

Coordinate systems used in the Czech Republic - Regulation No. 430/2006 Coll. on the determination of geodetic reference systems and state map works binding on the territory of the state and the principles of their use:

- World Geodetic Reference System 1984 (WGS84),
- European Terrestrial Reference System (ETRS-89),
- Coordinate system of the Unified Trigonometric Cadastral Network (S-JTSK),
- Cadastral coordinate system Gusterberg,
- Cadastral coordinate system St.Stephen,
- Baltic height system - after levelling (Bpv),
- Gravity system 1995 (S-Gr95),
- Coordinate system 1942 (S-42/83).

cadastral trigonometric network of 1st to 4th order (1824 - 1860), maps in scale 1:2 880:

- → cadastral mapping of the territory of former Austria-Hungary (1817-1864),
- large size and ruggedness of the territory → our republic divided into three parts in the direction of the meridians,
- the origins of coordinate systems (base points) are:
  - for Bohemia - trigonal point on the hill **Gusterberk** in Upper Austria,
  - for Moravia - the tower of the church of **Saint Stephen** in Vienna,



  - for Slovakia - trigonometric point on the hill **Gellerthegy** near Budapest.

Geographical location
Baltic elevation system after levelling

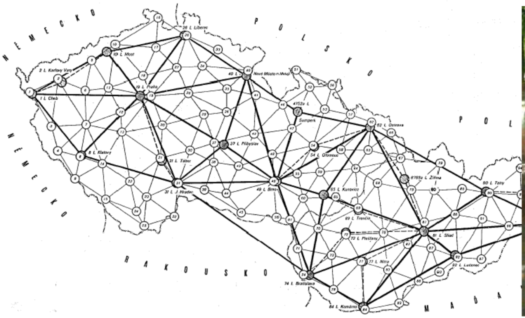
parameters:

- starting altitude point - zero scale of the sea water gauge in Kronstadt,
- a set of normal heights from international levelling networks.

$(H)_{Bpv}$

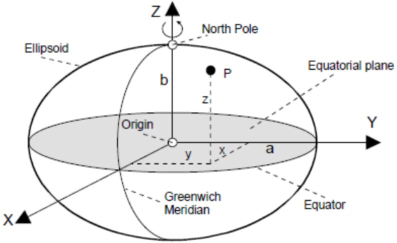
parameters:

- level and grid size, which are derived from absolute gravity measurements in the international gravimetric network,
- a set of gravitational acceleration values from the international grid alignment.



designed by:

- space geodesy technologies that are part of the system administrator's monitoring and processing centre programmes,
- a set of plane coordinates of points referenced to the World Geodetic Reference System 1984, epoch G873,
- ellipsoid of the world geodetic system 1984.

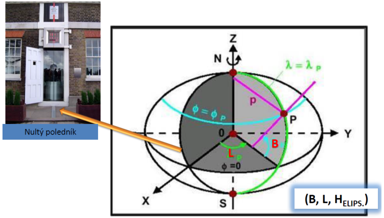


Parameter of WGS-84 Reference Ellipsoids		
Semi major axis a (m)	Semi minor axis b (m)	Flattening (1: ....)
6,378,137.00	6,356,752.31	298,257223563

- U.S. Army geocentric coordinate system, standardized for NATO militaries,
- a rectangular right-handed system rigidly linked to the Earth by a set of precise WGS-84 coordinates,
- UTM (Universal Transverse Mercator) display is used for maps,
- implemented on the basis of a modification of the NNSS maritime navigation satellite system,
- the origin of the geodetic system is located at the Earth's centre of gravity (geocentre) - identical to the centre of the WGS-84 reference ellipsoid,
- the Z axis passes through the reference pole defined by the IERS (International Earth Rotation Service) - identical to the axis of the rotation ellipsoid,
- the X axis is the intersection of the reference meridian plane and the equator plane (the plane perpendicular to the Z axis passing through the origin of the system),
- the Y axis completes the system on the right-handed orthogonal axis (it lies in the plane of the equator 90^o east of the X axis),
- the origin and orientation of the axes are realized by 12 ground stations of the GPS control segment,
- since 1.1.1998 WGS is implemented in military and civil aviation.od 1.1.1998 je WGS zaveden ve vojenském i civilním letectvu.

the position is expressed by:

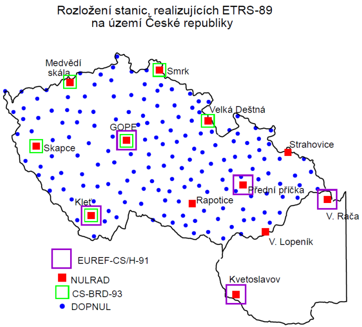
- orthogonal spatial coordinates (X, Y, Z),
- geographical coordinates: latitude φ, longitude λ, ellipsoidal height H_{el}



- orthogonal plane coordinates in Universal Transverse Mercator (UTM) and Universal Polar Stereographic (UPS) views for polar regions
  - E - Easting
  - N - Northing
- coordinates in the MGRS (Military Grid Reference System) reporting system.

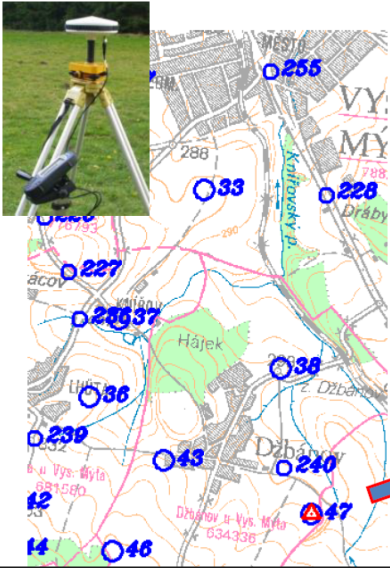
designed by:

- space geodesy technologies and constants that are part of international processing centers,
- reference frame of selected geodetic datum points whose orthogonal geocentric coordinates were referenced to the European Terrestrial Reference Frame, epoch 1989.0,
- ellipsoid of the 1980 geodetic reference system.



- ETRS (European Terrestrial Reference System) is a unified coordinate system - the implementation began with the advent of GPS technology,
- consists of a reference frame (a set of stars and points to which coordinates are assigned and changes in these coordinates over time) and a corresponding set of algorithms, constants and technologies,
- derived from the ITRS and connected to the Eurasian continental plate (annual time changes are max. in the order of millimeters) $\rightarrow$ does not have a constant position of the axes,
- is realized by coordinates of stabilized points on the Earth's surface,
- the system uses geographic coordinates $(\varphi, \lambda, H_{el})$ETRS and also rectangular coordinates (X, Y, Z) ETRS
- is based on the GRS-80 ellipsoid (Geodetic Reference System 1980), which is very close to the WGS84 ellipsoid,
- in the Czech Republic, the point fields for the JTSK system are linked to it,
- to a certain degree of accuracy, the coordinates of points in the ETRS and WGS systems can be interchanged.

Geodetická měření GPS

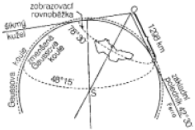


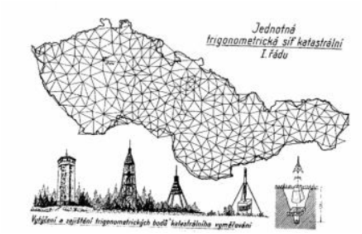
(B, L, $H_{ELIPS.}$) nebo (X, Y, Z)

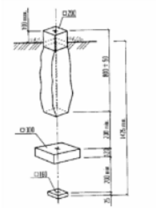
determined by:

- Bessel ellipsoid with parameters a = 6377397.15508 m, b = 6356078.96290 m, where a is the length of the main semi-axis, b is the length of the secondary semi-axis,
- Křovák conformal cone projection in general position,
- a set of coordinates of points from the alignment of trigonometric grids.

(Y, X)

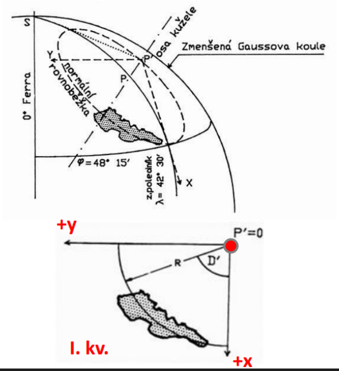




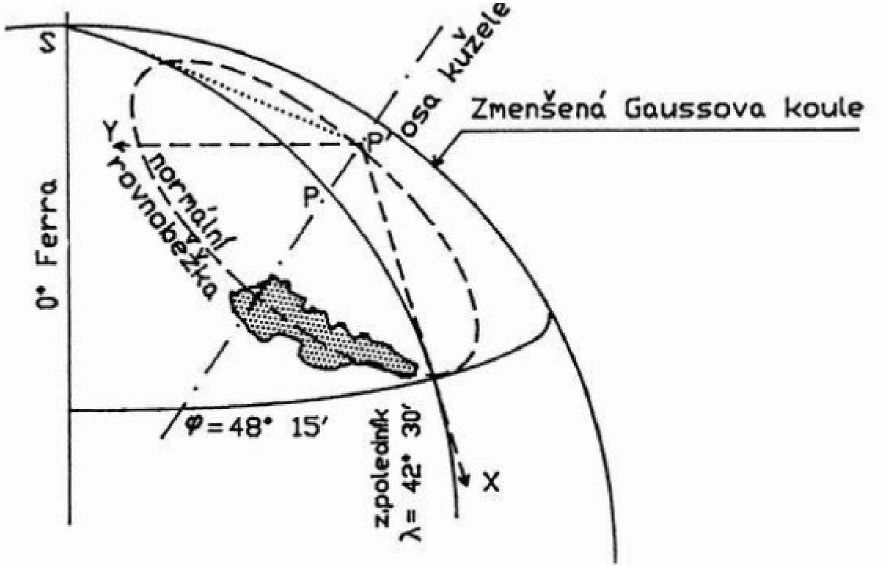


- After 1918, the need arose to urgently create a suitable geodetic system for the needs of civil surveyors.
- The Cassini-Soldner display could not succeed:
  - the new republic had three coordinate systems,
  - the old cadastral triangulation was inaccurate,
- under these circumstances, it would not be appropriate to "stretch" precise measurements into the imprecise triangulation fundamentals of the last century,
- Therefore, in 1919 the Triangulation Office was established ⇒ Ing. Josef Křovák.
- The task was to build reliable geodetic foundations (on the whole territory of the Czechoslovakia) as quickly as possible, including a suitable cartographic representation.
- Křovák finally succeeded with his cone display (mainly because he made conversion tables).
- In 1920 they started measuring work connected with the construction of a new network in Moravia and continued eastwards.

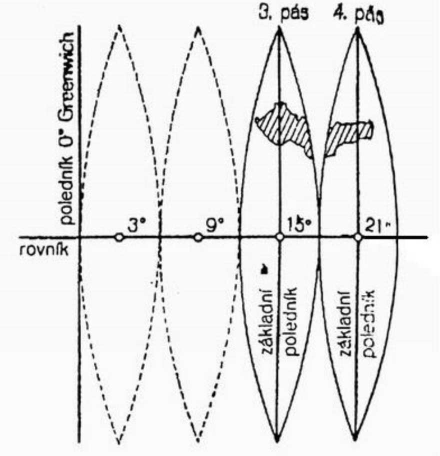
- In 1927 the surveying work was completed and the basic network, with a total of 268 points, was aligned,
- in 1928 work began on thickening the network with points of the second, third and fourth order and a detailed trigonometric network of the fifth order,
- measurement work was completed in 1958.

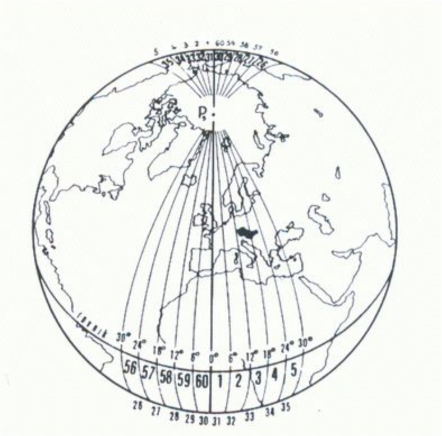


- **počátek** soustavy byl zvolen mimo území naší republiky - nad Finským zálivem (poledník 42°30′ východně Ferra)
- kladný směr **osy X směřuje k jihu**
- kladný směr **osy Y směřuje k západu**
- **celé území republiky je v prvním kvadrantu**
- **souřadnice všech bodů zůstávají kladné**
- pro celé území ČR platí, že **Y < X**


S
osa kužele
Zmenšená Gaussova koule
P
P.
Y
normální rovnoběžka
0° Ferra
φ = 48° 15′
z.poledník λ = 42° 30′
X

- used the North Pole system (positive X axis points north and positive Y axis points east)
- usage:
  - in non-public maps (for military purposes),
  - in some tourist maps
- determined by the Krasovsky ellipsoid with the Pulkovo reference point,
- Gauss - Krüger cylindrical (transverse) conformal representation is used,
- Earth's mantle divided into 3^o or 6^o belts (depending on the scale of the maps),
- numbering starts at 180^o and proceeds in an easterly direction,
- our territory lies in the third, partly in the fourth 6^o belt,
- each belt has its own coordinate system,
- the image of the prime meridian is the axis of the segments X (positive direction to the north),
- the image of the equator is the axis of the ordinate Y (positive direction to the east).

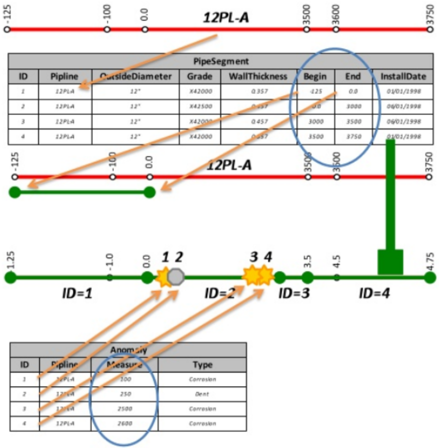

3. pás
4. pás
poledník 0° Greenwich
3°
9°
15°
21°
rovník
základní poledník
základní poledník


56
57
58
59
60
1
2
3
4
5

- there is a range of software for converting between different coordinate systems,
- currently most geoinformation systems contain transformation formulas and allows the conversion of coordinate systems,
- the starting coordinates are usually the geographical coordinates at reference ellipsoid φ, λ,
- in some cases (small scale maps) geographical coordinates on reference sphere U, V,
- the final coordinates are always the planar rectangular coordinates x, y,
- in practice, various combinations of transformation can be encountered:
    - military topographic map display is a direct transformation between geographic coordinates and planar rectangular coordinates x, y, The
    - display of the basic maps of the Czech Republic, on the other hand, is a gradual
        - geographic coordinates on the reference ellipsoid => geographic coordinates on the reference sphere $\Rightarrow$ cartographic coordinates => polar coordinates $\Rightarrow$ planar rectangular coordinates

- **continuous** - based on the continuous measurement of the position of geoelements, without step changes of coordinates and interruptions - according to the method of deriving the position of geoelements:
    - absolute,
    - relative - in relation to:
        - plane,
        - line - dynamic segmentation,
- **discrete**

dynamic segmentation - a coordinate system used to determine the relative position of geo elements relative to a starting point ("origin") along a given line (called **stationing**) - e.g. transport network managers



Thank you for your attention.