## Chapter 3

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# From Pyramids to Geomatics – Geodetic Aspects of Natural Environmental Investigation

### 1. Introduction

Geodesy is the science deal with determination of the size and shape of the earth and describing the location of a points on its surface. Maps are the result of geodetic field measurements and office works first of all, but also textual documents also having legal character. The name of geodesy was introduced by Aristotle and comes from the Greek language geo – earth and daiso – I will divide.

Geodesy realizes itself in a various disciplines, sometimes surprisingly distant from its alone. This illustrates the tree-diagram where in a transparent way is shown on Fig. 1. What is essential - this tree expands all the time. The new areas of operation of geodesy show this with the great success using technology which were borned just in second half of XX century and happened quickly the independent disciplines of the science. This concerns remote sensing, GPS and the spatial information systems incorporate the most modern solutions from the field recording and processing of images, satellite navigation, computer science and transport.

By the traditional map we understand model of the geographic reality presented in a graphical form (drawing or pictorial) with the use of the scale and understandable for the users cartographical symbols (Gaździcki 2001).

In ancient times map preparing was limited to the technical possibilities of the survey of topographical details. In the Middle Ages it was restrained to the measurements in a local scale. At that time the definition of the scale was know and appled in a practice. The angles were measurements using simple instrument called James' cane. Topography and position (geographical data) were measured by the intersection method. Geodetics be able to determine geographical latitude and longitude from stars observation. The method of the triangulation was applied in XVII century (Fig. 2a), which together with astronomical measurements, made possible maps preparation in the uniform system for the whole country. In these years military needs were the main reason of map production. In XVIII and XIX century applying table measurements (Fig. 2b), military topographical corps prepared topographical maps for the whole Europe.

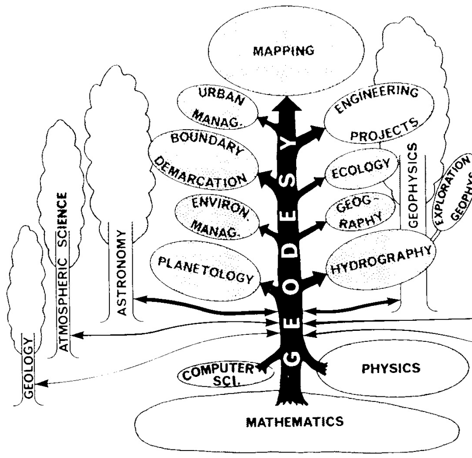
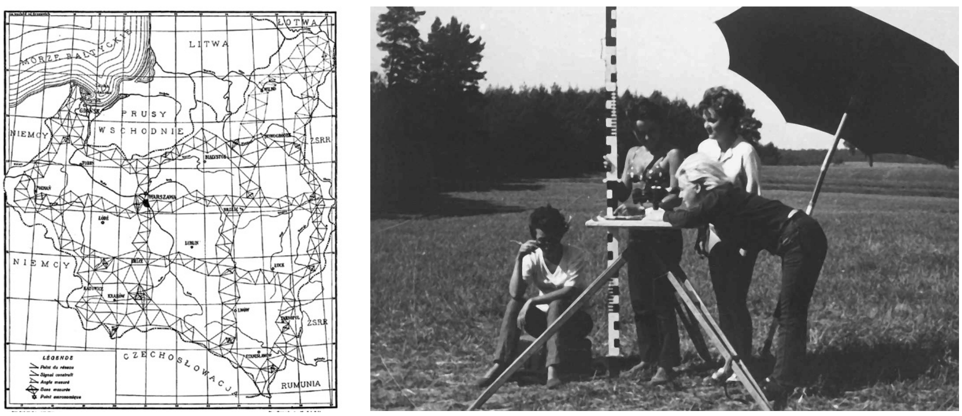



Fig. 1. Relation of geodesy to another disciplines (Vaniček and Krakiwsky 1982)

In order to prepare maps of the wide areas of remaining continents the more advanced technology of mapping was necessary. Such technology appeared the photogrammetry. The maps of remaining continents were prepared thanks to photogrammetry in the time of II World War. After II World War this technology was applied in developing countries such as e.g. Argentina. At present thanks to the photogrammetry almost the whole earth is covered by maps in a scale 1:200 000. In the case of the more useful scale (this is the scale 1:50 000) only 2/3 of the globe is covered by this scale. However these maps are usually less up-to-data, particularly in a developing countries.




a b

Fig. 2. a) First order triangulation network in Poland before 1939, b) table topographic survey in Poland in 1965

In recapitulation of this chapter one should state that the classical methods of map preparation were based on difficult field measurements, even in the a case of photogrammetry. These measurements were done using the simple measuring instrument. The results of measurement were written down in a suitable field books (paper) and maps were drawing on carton by hand what gave unusually long process of such maps production. As the result of this process only one copy of a map was prepared.

## 2. Digital map

The technique of maps drawing and their use was changed drastically with a appearing of the computers. Computer cartography is the maps production by using computers. The final results of geodetic measurements can be gather in the digital form and processing effectively in the computer. The computer does not only delivers the practically unlimited area of the memory, but it also lets on storage of the digital maps separately from the printed forms or displayed on the screen of the monitor. In that way geodetic data (geographical data) can be kept in the original form without the loss of their accuracy.

By the digital map we understand the model of the geographical reality introduce in the digital form and adapt to the computer processing of geographical data and to generating analog maps of selected area (Gaździcki 2001).

Exist many variants of digital maps production. Two simple methods of digital map making were showed on Fig. 3. In the first case the field measurements were done by the modern electronic tachymeter which makes possible the measurement of directions and distances in the automated mode. The results of the measurements are written down in the memory of tachymeter and then in the office are transmitted to the computer.

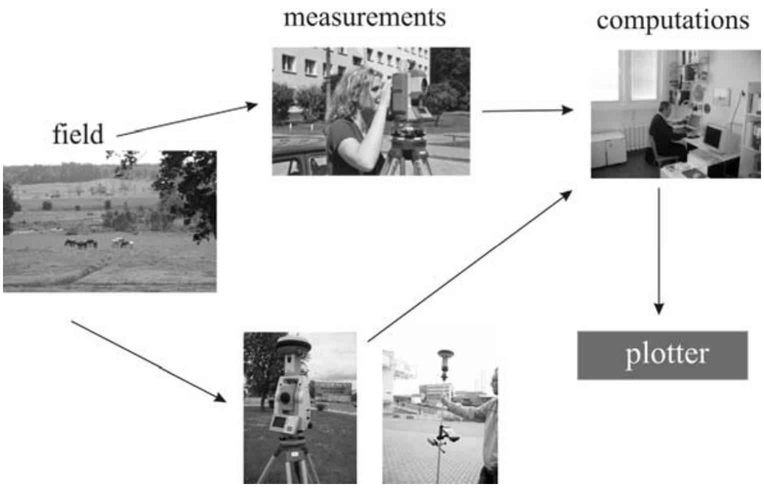



Fig. 3. Principle of creating digital maps

One using simple computer programmers' e.g. „Winkalk" can compute the coordinate of all field details. The points in which the coordinates was computed can be displayed on the screen of a monitor and joint then properly giving the map in a digital form. The simple „MikroMapa" software makes possible. drawing the map on the screen of the computer. The more advanced software to digital maps drawing is wildly used in Poland is „C-Geo" or „Geoinfo".

Recently for the measurement of a field details (geographic data) more and more often is used GPS satellite technology in the version of RTK (Real Time Kinematic). This technique is more effective than use of electronic tachymeter, because it delivers the coordinate of measured points directly in the field and does not depend from the weather conditions. One can e.g. find more details on that subject e.g. in paper Kowalczyk and Węglicki (2010). RTK measurements are not possible when satellites of the GPS system are not visible (e.g. in urban measurements with the high buildings or in forests). Therefore the Leica company combined the electronic tachymeter with the GPS receiver and constructed instrument called smart station which is showed in the bottom part of Fig. 4. This instrument is the newest trend relating the conception of the measurement of topographical details (geographic data) and it will dominate market in the near years.

More advanced methods of digital maps creation are called GIS. GIS is the shortcut from English technical term Geographic Information System introduced in the second half of the sixtieth years of XX century. It descends from the name of the informative system created for Canada. It was at a time the first system introducing the new and different from another information systems methodology of logging, storage and analyzing data. In the next chapter will be introduced general information concerning the geographic information systems. The unusually numerous literature exists on the subject of GIS. The basic information relating GIS which was used in the present work comes from the textbook Bielecka (2006).

## 3. Geographic information systems

GIS means the system of collecting, storing, actualization, management, analyses and making accessible data referred to the surface of earth (geographic data) (Gaździcki 2001).

In the wide understanding GIS means the system of the flow and utilization of the information and contains the technical resources i.e. computer equipment and software, methods, the database, procedures and human and financial resources indispensable to functioning the system. In the end of eightieth of XX century, the term GIS also begins means the scientific discipline interesting in geographical information, methods and GIS techniques (geographic information science) named later geomatics or geoinformatics.

GIS link up the data relating the location of a objects with the character of these objects. These data can be written down in various formats and come from many sources. The storage of the data in one, coherent geographical database, lets on quick obtainment of the answer on the question and execute the analyses, what improves decision making considerably. Thanks to the complex analytic possibilities and visualization, GIS helps in recognizing and the understanding of the relationship and rules ruling in the surrounding us world.

GIS from another information systems differed the technology. That is set of tools, named software (packages) of GIS type, allowing to analyze the geographical and descriptive data and the presentation of these analyses in the cartographical form. Therefore many persons, particularly the representatives of commercial firms, restrict the understanding of GIS to the technical aspect, and thing closely to the software only.

In the end of eightieth of the last century in the literature relating GIS appeared term SIS (Spatial Information System) and LIS (Land Information System). At present ones considers that the spatial information systems divide on the geographic information system GIS and the of the land information system LIS. The difference among GIS and LIS results from the stage of detail of information kept by the system. More detailed information representing maps usually in larger scales than 1:5 000 is collected in the LIS systems. However generalized data are keep in the GIS system for maps in smaller scales then 1:5 000. In the many English publications majority of authors treats GIS and LIS as synonyms using them interchangeably.

### 3.1. Systems design Transition

Design the geographic information systems joins with transfer of the real world to its representation in the computer. Creation of the geographic information systems is the multi step process. Transition from the real world to its representation in the computer requires the knowledge of processes and phenomena occurring in the real world, then the preparation of conceptional model, logical model and on the end physical model, and also designing maps and other special final products (Table 1).

Modelling processes and phenomena is strongly connected with the purpose and the tasks of the system and should be executed by users system, experts from the given field. The model of the expansion of the pollutions of an air will be different from the model of the pollutions of a soils. What more, both will differ considerably, when we consider them in the scale of the country or the commune.

The knowledge of modeled objects and phenomena makes up the basis to the study of conceptional model. Conceptional model operates the high degree of the abstraction, is independent from the implementation and often prepared in natural language. We describe it in the thematic and spatial range of the data base, accuracy and the data details, the types of the data and the way of their representation.

Conceptional model should be created by the team consisting from future users, experts from the field of GIS and computer scientists. This model makes up the basis to preparing more detailed logical model.

Table 1

Steps in transition from the real world to GIS (Bielecka 2006)

| Phase of GIS creation | Action |
|---|---|
| Modelling of the real world | The recognizes of the processes and phenomena of the modeled reality and the creation of the indispensable models. |
| Conceptional model | Thematic and spatial range of the data, accuracy and the detailed of the data, types of the data and the way of their representation. |
| Logical model | Description of the modeled segment of the real world using the rules and accessible methods within the accepted data model. |
| Physical model | Creation of the physical structures of the database. |
| Implementation and exploitation | Data collection. Analysis of the data. Presentation of the results of analysis. |

The process of logical modelling is connected with the description of the modeled segment of the real world using the rules and accessible methods within the accepted data model. If on the stage of conceptional model we accept model of the data, then the logical description will be expressed as relational scheme.

The last stage of data modelling is a physical model, dependent on the hardware-software implementation. Separating of the logical modelling from physical modelling makes possible the implementation of the database on many various ways, that is utilization of the various system of the management of the database (Database Management Formation).

### 3.2. Elements of Geographic Information Systems

Basing on the definition of GIS, formulated by Gaździcki (2001), the geographic information systems consist from:

- computer equipment,
- software,
- data,
- procedures to management and analyzing data,
- people.

Computer equipment and software are the indispensable technical resources to functioning GIS. In the face of the variety of customers requirements and the accessible of software packets, the geographic information systems can be created on the base of any computer equipments, having conceived from mobile computers through stationary personal computers, working stations, and also computers with the large computational power.

From the technical side, GIS can function on single computer or several joint into the net computers to which problems connected with management, analyzing and the visualization of the data are assigned suitably. Projecting the geographic information systems you should adapt equipment to the nature of realized problems, and particularly time-consuming processing of spatial data and choosing to this suitable processor, quick and capacious disc, the supplies of the memory of RAM, the monitor and peripheral devices to introduces and leading out data such how the scanner, digimetr, plotter and printer.

System, tools and application software fulfill the role of the integrator of all units of the system. It possesses the functions to preliminary data input, processing (e.g. the conversions of formats), the storage, management the database, tool to the analyze of the spatial data visualizations and the user of graphic interface, enabling using the functions of the system. The choice of GIS software tools influences on the way of the solution of the specific problem. Suitably to the accomplished choice, we have in the result at the disposal the larger or smaller functional possibilities of the system.

The data are the most important element of the system. The basic features guaranteeing the high quality of the spatial data is: accuracy, timeliness, credibility and completeness. Accuracy joins with the detailed description of the data, timeliness with their compatibility with the modeled world, credibility talks about the confidence to the data, and completeness about compatibilities accumulated data with put on the beginning requirements relating both content, and the area.

Because the process of collecting the detailed data is remarkably time-consuming, complex and expensive difficult technically and organizational, therefore you should collect in the geographic information system only indispensable data, letting to get specific results in the possibly short time and on the minimum cost. In preparation of the concept of the system and projecting the structure of the database you should act according to the principle of pragmatism, needs of the future users of the system and the accessibility of the source data.

Data are kept in the database. The database is not only the set of the data, but also the system of the management of this database, which is enabling the access to the data. GIS database have its distinction connected with storage spatial data. The majority of GIS system tools keeps data geometrical separately from descriptive information, including the attributes of the geometrical data. Geometrical data are kept in the set of the files of the operating system with the direct access, and descriptive data dependent on standardization are written down according with convention adopted in a typical system of relational database. GIS software administrate connections between geometrical files and descriptive data.

People are very essential component of the geographical information systems. They plan the system, initiate, use and undertake decisions using data storaged in the system. The success or failure of GIS implementation in a large degree depends from „the human" factor than from the technical resources. In the majority of institutions, where GIS is implemented organizational changes are introduced. Accepting these changes, efficient management and utilization of GIS in the process of making the decision are the basic factors guaranteeing the success implementation of GIS systems.

## 4. Sources of geographical data

Geographical data, called also spatial data or geodata, are data describing objects which are defined in the relation to the surface of the earth. They can be obtained from existing maps, from traditional field measurements, from satellite observations, from photogrammetric, scanner and satellite digital images.

### 4.1. Analogue maps

Analog maps are very popular source of the data for GIS. When the database is created first time, then the digitalization of existing maps is the quickest and the cheapest way of obtaining the geodata, though these data are characterize not high accuracy. One can change the analog map into the digital form by vectorization or scanning (Young_Qi-Chen and Yuk-Cheung Lee 2001).

### 4.2. Ground-base positioning techniques

The measurement of distance and angles is the basis of traditional field measurements. One can mark the position of point (its coordinate x, y) and height in a respect to the mean sea level on the basis of this type of observations. At present to the measurement of distance the electronic tachymetry is used which make possible writing down the results of the measurement in the memory of the instrument and then their transfer to the computer where calculation of necessary quantity are done and digital maps are created (Łyszkowicz 2006).

### 4.3. Satellite positioning techniques

Satellite measurements based on the use of the global positioning system GPS (Global Positioning System) which in a last years is used in all kinds of geodetic works and in navigation. The advantages of satellite technique such as: high accuracy, possibility of the immediate obtaining of the position, almost the complete automation of measurements and their adjustment and considerably lower costs decided about its wide use in the comparison with traditional ground-based techniques. GPS measurements serve to determining the position of a stable control points and also objects being in movement (Czarnecki 2010).

Satellite GPS measurements consist on the measurement of distance from satellite receiver to the satellite. The measurement of distance can be carried out in a code mode (pseudorange measurement) or phase mode (phase measurement). The accuracy of the distance measurement by the code method is about ±3 m, while the accuracy of the phase measurement is of the order of ±2 mm. The point coordinates can be determine using various methods. Recently generally applied method to geodata collecting is RTK method.

The term RTK refer to the phase method of satellite measurements, in which point is determined by the mobile receiver and improved in the real time from utilization of observations data sent from the basic station. In such a case two GPS receivers are indispensable. In the case when we use corrections emitted by Active Geodetic Network ASG-EUPOS in survey of a geodata only one receiver is necessary, what means that such kind of measurement is about half cheaper then with two receivers. The accuracy of RTK measurements is about 1-2 cm.

### 4.4. Image acquisition

Images in a such or another form are significant source of information for GIS. The images can be classified in the various way, because of their (digital or analog) type, the device uses to their acquisition (camera or linear scanner), and the place of their realization (airplane or satellite). All types of images and the ways of getting them are well explained in the textbook e.g. Qi-Chen and Yuk-Cheung Lee (2001).

The air laser scanners make possible the measurement of a coordinate points located near each other on the surface of the earth. The final product of such laser scanning is digital terrain model (DTM). This technology is very effective, because its penetrate the physical surface of the ground and does not depend on weather condition, and moreover the laser penetrates the vegetable cover. Laser scanning apart of utilization to constructing exact DTM is used to inventory of elongated objects like roads, power lines and embankment.

Satellite images are the best source of information for spatial data. Remote sensing is that part of geodesy which deals with how getting out from images information. The quality of satellite images is characterized using the spatial, spectral and time resolution. The spatial resolution informs about the size of the pixel, the spectral resolution is the ability of recognizing the various frequencies of the electromagnetic radiation. However the time resolution defines, after how many days the satellite will observed the same part of the terrain.

Presently many remote sensing satellites orbiting around the earth which products can be use to creating the database of GIS systems. From among remote sensing satellites one should mention the satellite of the Landsat type which circulate on the orbits from 1982. The last satellite of this type gives the images with the spatial resolution 15 m x 15 m and very large spectral resolution.

Another satellites that images can be used as the source of the geographical data is French satellite SPOT, Indian satellite IRS, satellite IKONOS, Quic-Bird and EROS (Sanecki 2006).

Monopoly on placing by government agencies on the orbits large and heavy satellites was broken through the private firms which began produce mini or micro satellite and place on them tiny sensors to the observation of the earth. To such mini satellites are included numbered satellites as: GeoEye, Sentinel, Envisat and another.

References spatial data should to be referred to the uniform geodetic frame. In the next chapter will be presented global geodetic system ITRS and geodetic reference frame ITRF and the way of its realization.

## 5. Coordinate system, reference system and reference frame

Spatial data relating to the earth and all objects connected to it have to be expressed in the uniform geodetic frame. In this purpose is necessary well defined coordinates system, the terrestrial reference system and the terrestrial reference frame. In the present chapter we will introduced basic information on this subject and then we will explain global terrestrial frame ITRF and current geodetic reference frame in Europe and in Poland.

### 5.1. Coordinate system

In present geodesy, for global problems, the three-dimensional Cartesian system of coordinates is applied. It is defined by three orthogonal axes which create the right-handed system. Coordinate axes X, Y, Z cross in the beginning of the system like it is showed on Fig. 4. The point P is defined through distance from the initial point O counting along the axis X, Y and Z.

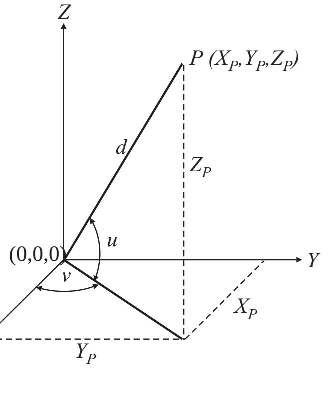



Fig. 4. Ortho-Cartesian three-dimensional coordinate system

Second commonly used in geodesy system of coordinates is the ellipsoidal curvilinear system. The location of any point P in this system is defined by the ellipsoidal latitude $\varphi$, ellipsoidal longitude $\lambda$ and ellipsoidal height h (Fig. 5).

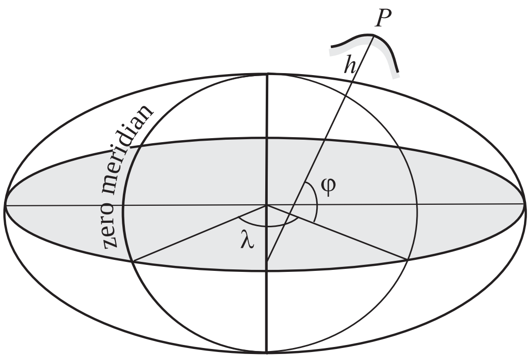



Fig. 5. Ellipsoidal (geodetic) coordinate system $\varphi$, $\lambda$, $h$

### 5.2. System and reference frame

The coordinate system does not contain any information about its orientation in respect to the earth mass. These information are included in the description of a reference system. We define the reference system as the set of parameters and the recommendations together with the description of indispensable models including origin of the system, scale and the orientation of axes and the variation of these parameters in time.

Reference frame establishes the practical realization of the reference system. The computed from the observations values of parameters describing origin of the system, scale and the orientation of the axes and their variation in time consist on the reference frame.

At present in geodesy is used global reference frame named International Terrestrial Reference Frame (ITRF). This system was introduced by International Union of Geodesy and Geophysics (IUGG) in 1991. Organization responsible for the realization of the ITRS system was appointed in 1987 by IUGG, International Astronomical Union (IAU) and International Earth Rotation and Reference systems Service (IERS).

### 5.3. International Terrestrial Reference Frame ITRF

ITRF system is a kinematic system. It is defined by the stations coordinates *X*, *Y*, *Z* (Fig. 6) determined within the IERS service, chosen on the particular epoch t0 and their derivatives in relation to time (speed of a points) together with the estimation of accuracy. First realization of the IERS system was on the epoch $t_0$=1988.0 and it carries name ITRF88. In the realization of ITRF88 the observations from three satellite techniques were used: VLBI (*Very Long Base Interferometry*), SLR (*Satellite Laser Ranging*) and GPS (*Global Positioning System*).

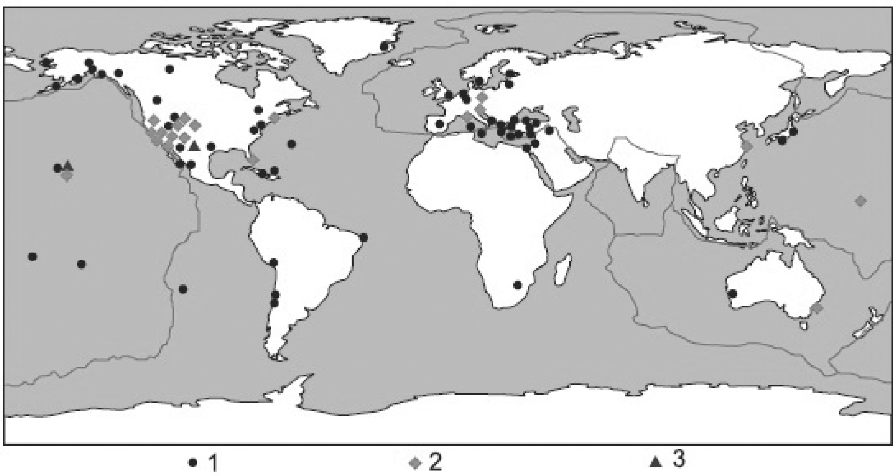



Fig. 6. Location of the base stations defined the ITRF88 reference frame and type of observations realize on them (source: http://itrf.ensg.ign.fr/)

The idea of creation of a new precise reference system for Europe came into being of 1987. Then the suitable Subcommittee EUREF was established, which was engaged in scientific aspects of this mission. Simultaneously professional organization CERCO (*Comité Européen des Responsables de la Cartographie Officielle*) was engaged in practical aspects from the point of view needs of geodesy and cartography and made appropriate decisions. The result of works of both organization was *European Terrestrial Reference System* (ETRS).

*European Terrestrial Reference System* is the subset of the system ITRS. For the assurance of compatibility with the ITRS system to ETRS the network of European SLR stations (8 station) and VLBI stations (7 station) took part in defining the ITRF89 system (Rogowski and Figurski, 2004). ETRS system is now the realization of the ITRS system on the epoch $t_0$ = 1989.0 (ITRF89), by the assumption of the stability of the Eurasia plate. This solution carries name ETRS89 and makes up the geodetic reference system for the majorities states of Europe.

Taking into consideration movements of the Paleozoic Central and Western Europe platform in respect to ITRF, the realization of the reference system ETRS89 (ETRF) does not agree with the current ITRF system in the epoch of the observation. It results the need of transformations determined coordinate in to the system ETRF as the realization of the ETRS89 system. Such transformation can be done using procedures given by Boucher and Altamimi (2008).

Practical realization of terrestrial reference frame ETRS89 (EUREF-89) comprises positions of 35 European SLR and VLBL stations included in ITRF and determine at the epoch 1989.0. This set was recognized as the set of coordinates defining European terrestrial reference frame ETRF. So now ETRF is the subset of the global solution ITRF for the epoch 1989.0.

Because of the tectonic movements of the continents the terrestrial reference frame ETRF changes its position slowly in relation to ITRF with the speed about 1 - 3 cm per year, however it almost does not suffer of the internal deformations. therefore one can define the initial epoch, and then determine regularly (once on 10 years) parameters of transformation in relation to the reference system WGS84 and ITRF (Łyszkowicz 2006).

In the half of 1992 the European the reference system EUREF were spread out on the territory of Poland. The initiative of this project was proposed by the group the scientists focused in the Section of Geodetic Networks of the Committee of Geodesy Polish Academy of Sciences (Baran and Zieliński, 1992). This group also worked out the project of the configuration of the Polish part of EUREF network and named it EUREF-POL.

The proper campaign observational GPS took the place in 4-8 July 1992. Together with 11 points from Poland in the campaign participated 19 stations and observatories from different European countries (Fig. 7), assuring in this way tied of EUREF-POL network to the existing already network EUREF (Baran and Zieliński 1992).

The network EUREF-POL was measured two times, namely in campaign in 1992 and in second campaign in 2001. This network was adjusted in respect to the IGS European reference stations.

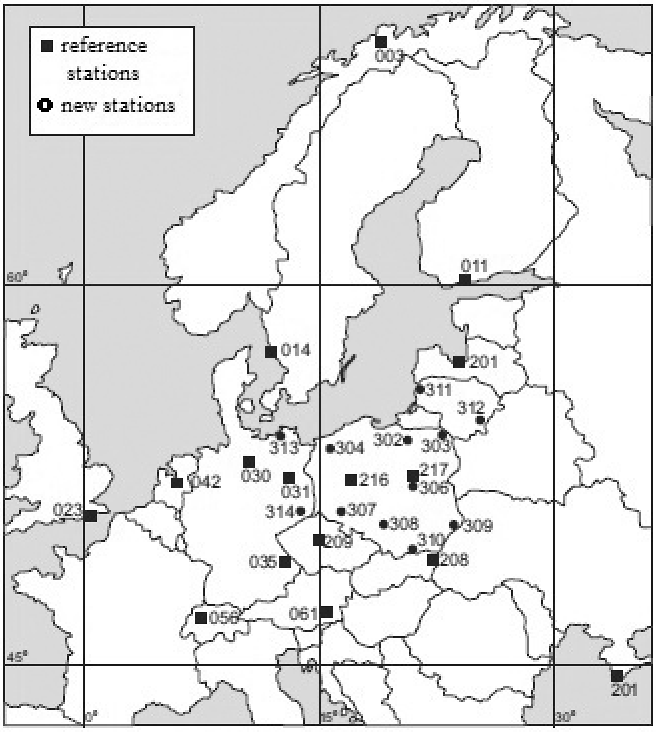



Fig. 7. Location of stations in EUREF-POL’92 GPS campaign

The second adjustment of the EUREF-POL network in 2008 confirmed that the changes of the coordinates do not exceed 0.5 cm in horizontal component and 1 cm in vertical component. It means, that the EUREF-POL network does not require the urgent modernization, what is essential, that it she this network became in the connection to it the lower order network was measured and adjusted (Bosy et al. 2008).

## 5.4. POLREF network

In 1994 began the densification of the EUREF-POL network. In result the three GPS observational campaigns were conducted in years 1994-1995.The network consists from 348 points distributed uniformly on the area of the country. This network is called POLREF (POLish REFerence Frame) and was tied to 11 points of the so called “zero order” network EUREF-POL (Fig. 8). In this project GPS also were used observations from the IGS permanent stations such as: Józefosław (JOZE), Borowiec (BOR1) and Lamkówko (LAMA)

Distances between the points of the POLREF network are about 30-35 km. Total time of duration of all three GPS campaigns during POLREF network measurement was about two months. In this time about 5 700 000 observation was made, which were used to compute the coordinates of the network points.


Fig. 8. Points of EUREF-POL and POLREF networks

Especially designed monuments were placed at the network points and make possible caring out not only satellite observations, but also levelling and gravimetric measurements. Bernese the final adjustment of the network POLREF was made using Bernese GPS software and the network was tied to 11 EUREF-POL points. The accuracy of coordinates of POLREF points, computed in the EUREF-89 system, for horizontal coordinates is much smaller from ±1 cm in relation to EUREF-POL points, however for height component should be estimated on about ±1 cm (it means, that the relative error of a side is on the level of $1 \times 10^{-7}$ or less). POLREF points were also tied to the national vertical control network which is network of normal heights in Kronsztadt86 vertical reference system (Zieliński et al. 1994).

### 5.5. System of precise satellite positioning ASG-EUPOS

The multi-functional system of satellite precise positioning ASG-EUPOS was activated by GUGiK in June 2008. The 75 new reference stations were installed on the area of Poland (8 equipped in the unit receiving GPS/GLONASS signals) and the computational infrastructure was set up in the two computational centers in Katowice and Warsaw.

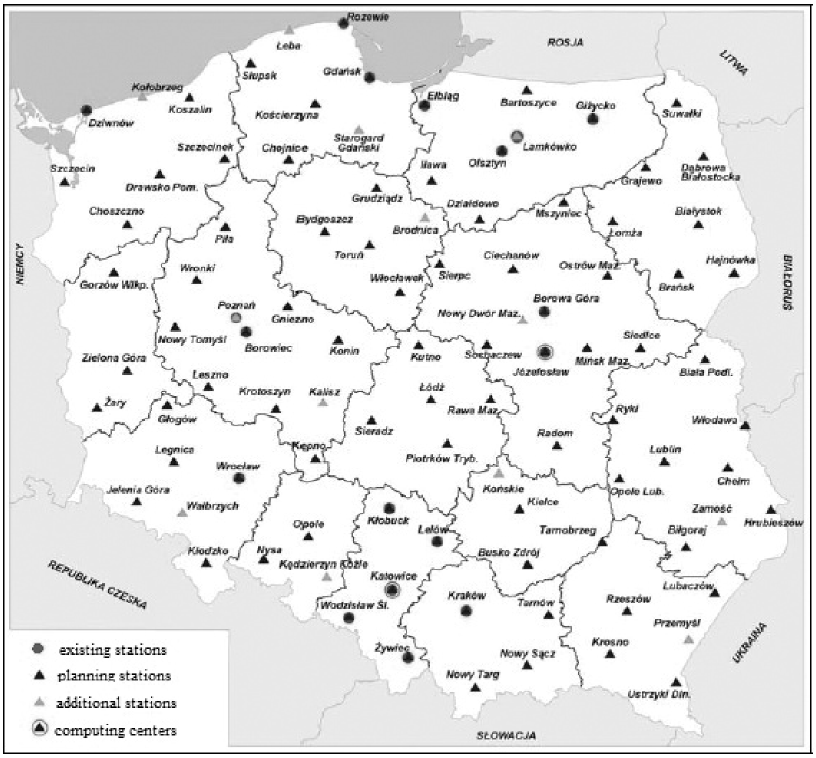



Fig. 9. Distribution of ASG-EUPOS stations in Poland (www.asgeupos.pl)

In order to assure the uniform distribution of points, additionally 22 reference stations on the territory of the Poland were included to the system i.e. managed by universities, research institutes, state administration and private firms. Also about 30 border stations from neighboring countries (Fig. 9) were included to the AGS-EUPOS. So the stations of the ASG-EUPOS system evenly cover the whole area of country (Bosy et al. 2008).

The ASG-EUPOS system enable to the user equipped only in one GNSS receiver determination in the real time of the position in any place on the area of Poland with the accuracy ± 2 cm (RTK mode) to ±3 m (DGPS mode). In post-processing accuracy ±0.5 cm can be achieved.

The basic aim of the establishes of the ASG-EUPOS network is making accessible in the mode on-line on the area of Poland corrections to measurements carried our by the GNSS satellite receivers and the creation the uniform in the scale of the country stable geodetic spatial references frame.

### 5.6. Geodetic reference system WGS84

This system is American satellite navigational GPS system. The system *Word Geodetic System* - WGS60 was created by the *Defense Department* of United States in 1960. The important growth of numbers and accuracy of satellite observations, which was in first years after introducing this frame, enable the produces next and more exact versions of the WGS60 system, namely: WGS66, WGS72 and then WGS84. This system is realized by coordinates of five observational stations lying on various geographical longitudes near the equator.

The GPS receivers after the reception of the signals from satellites circulating on orbits around the earth, determine the position of a point on the surface just in this in this system. These coordinates can be transformed to any different system, if the parameters of the transformation are known. Readers who are interested in questions of the transformation I send back to the papers of Kadaj (1999, 2000 and, b, c, d).

### 5.7. National Spatial Reference System

National geodetic reference system, called National Spatial Reference System, is used in geodesy, cartography and spatial information systems. It was introduce by the Government in August 2000.

This system consists on the geodetic reference frame EUREF-89, vertical reference system Kronsztadt86 and rectangular 2D coordinate system called "2000" for the base map and system "1995" for the map in the scale 1:10 000 and smaller.

## 6. Traditional and satellite methods of height determination

Every topographical map contains information relating situation and height of the particular area. The topography of the terrain is represented using the contour lines which are interpolated between characteristic points (station points) measured in the field. In order to determine the height of terrain points there is need to tie the measurements to the vertical control network (basic or detailed) which establishment is unusually laborious, time consuming and expensive job.

### 6.1. Spirit levelling

Usually since years one uses the geometrical and trigonometric levelling to the establishment of vertical control networks and to determination the height of terrain points - tacheometry.

Geometrical levelling is realized using levelling instruments and the set of rods. Levelling instruments are analog or digital, these last make possible considerable decrease the number of gross errors. The mean error of the height differences measured by the geometrical levelling oscillate at the level from 1.0 [mm] $\sqrt{L[km]}$ at measurement of a precise levelling networks to 10 [mm] $\sqrt{L[km]}$ in engineering measurements, where $L$ is a length of the levelling section in kilometers. At present it is known, that the best digital levelling instruments do not make possible the measurements of the height differences with so high accuracy as precise analog levelling instruments, but their use is considerably easier and the possibility of a commission of a gross errors however is almost impossible.

The length of the levelling line which we were adopted in the present work to further analyses are from 1 km to 100 km. Suitable mean square errors are given for these distances in Table 2.

Table 2

Mean square errors of spirit levelling (in millimeters) for chosen distances

| Length L of a section in km | 1 km | 10 km | 50 km | 100 km |
|---|---|---|---|---|
| Precise levelling: 1mm $\sqrt{L[km]}$ | 1 | 3 | 7 | 10 |
| Engineering levelling: 10 mm $\sqrt{L[km]}$ | 10 | 32 | 71 | 100 |

## 6.2. Trigonometric levelling

Trigonometric levelling depends on the measurement of vertical angle and distance between two points. In this purpose one uses the theodolite with mounted stadia. This method is considerably quicker than geometrical levelling, but gives somewhat lower accuracy because of the phenomenon of refraction. The errors can be reduced considerably through simultaneous trigonometric measurements. The trigonometric method can be motorized. Such option was used by IGN to the measurement of the national vertical control network in France in 1982 .

Recently since appeared very precise satellite GPS measurements then the new possibility of height determination called "GPS levelling" is possible. The idea of this method will be presented in the next paragraph.

## 6.3. GPS levelling – basic principle

The height of the physical surface of the earth is defined as the height above the mean sea level which can be consider as the level surface. If this surface, in the imagination, is extended under lands, then we will receive the level surface enclose the whole earth. This surface is called *geoid*. Differences between the physical surface of the earth, geoid and ellipsoid are showed on Fig. 10.

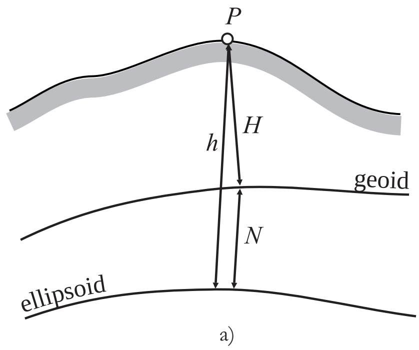



Fig. 10. Differences between the physical surface of the earth, geoid and ellipsoid

As is known heights from GPS measurements are not heights which we meet in engineering every the day. These heights are counted not from the mean sea level but from the ellipsoid. Fortunately, ellipsoidal heights *h* from GPS measurements, can be easily transform onto height referred to mean sea level using the following formula

$$H = h - N \tag{6-1}$$

Distance *N* geoid separation from the ellipsoid, presented in this formula, is on the territory of Poland from 28 to 43 meters.

This method is called the absolute method of height measurement and as many absolute methods are generally less precise than relative methods.

We usually can get one millimeter accuracy if we carry out the relative survey of height differences between two points and then applied the formula () in the following form

$$\Delta H = \Delta h - \Delta N \tag{6-2}$$

This means that to measure height difference $\Delta H$ you should use in practice simultaneously two GPS receiver, since from simultaneous GPS measurements the ellipsoidal height difference $\Delta h$ is determined. Additionally information about the geoid difference $\Delta N$ is necessary. The results of the measurement by such method are very precise, because the errors of the observation almost in the same way disturb measurements on both points, and in the result the difference the height is free from their influence. This situation is analogous to well known us levelling survey, in which we read the rod backwards and forward. At the reading backwards and forward we commit almost the same errors. The difference of reading give us obviously height difference free from these errors.

From the formula () results that the height difference from the classic levelling is not equal to the height difference from GPS measurements because of the term $\Delta N$ which on the territory of Poland has the value about 10 cm per 1 km. It means that in the case when satisfies us accuracy of height difference of the order 10 cm per 1 km, the term $\Delta N$ can be neglected and we can accept that $\Delta H \approx \Delta h$. In every another situation the knowledge of geoid is indispensable.

## 6.4. Methods of geoid investigation

Fundamentally there are two methods of geoid determination. The first method based on the description of geoid distance *N* from the ellipsoid using the infinite series of spherical functions (*spherical harmonic*), which simplified form is (Łyszkowicz, 1995)

$$N = R\sum_{n=2}^{\infty} \sum_{m=0}^{n} \left(C_{nm} \cos m\lambda + S \sin m\lambda\right) P_{nm}\left(\cos\theta\right) \tag{6-3}$$

where $C_{nm}$ and $S_{nm}$ are certain coefficients and $P_{nm}\left(\cos\theta\right)$ is the Legendre'a function.

The knowledge of these coefficients is indispensable in the practical calculations of geoid distance from the ellipsoid.

The first determination of 64 initial coefficients of this series was executed in Smithsonian Astrophysical Observatory in United States in 1966. The set of these coefficients was named model SAO-SE. This model enables determination the distance between geoid and ellipsoid for any point on the Earth sphere with accuracy about $\pm$ 8 meters.

In the sequence of the last 30 years the next coefficients of spherical functions series were computed and different models were created e.g.: GEM-10B, OSU81, OSU91, EGM96 and the last model in 2008 named EGM08. The accuracy of these successive models improved and during 30 years increased 40 times (Fig. 12). Last model named EGM08 contains over 4 millions coefficients and the calculation of N is possible with accuracy about ±2 cm on the territory of Poland (Łyszkowicz 2009).

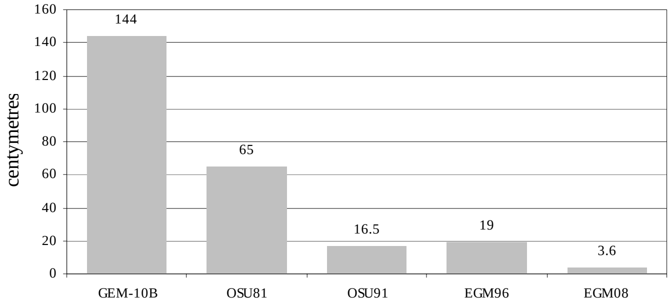



Fig. 11. Accuracy of N from the successive geopotential models

The second method of geoid determination based on integration of gravimetric anomalies according to Stokes formula

$$N = \frac{R}{4\pi\gamma} \int_{s} \Delta g \, S(\psi) d\sigma \tag{6-4}$$

where $R$ is the mean radius of the earth, $\gamma$ is mean earth acceleration, $\Delta g$ is the gravimetric anomaly, $\psi$ is spherical distance between determined point and unit d$\sigma$, $S(\psi)$ is Stokes'a function and $d\sigma$ is the unit of the surface of integration. Integration runs all over the surface of the earth. This means in practice that in order to compute single distance between geoid and ellipsoid the knowledge of gravimetric anomalies in every point of the earthly is required.

When in 1849 Stokes derived his famous formula, then and by many next the years, the lack of the sufficient number of gravimetric measurements made impossible its practical realization. This situation changed radically in the seventieth years of the last century, when the number of terrestrial gravimetric measurements exceed several tens of millions and satellite altimetric missions delivered valuable information about the gravity field on inaccessible until now areas of sea and oceans covering about 70% of the surface of the earth.

The first gravimetric geoid (*geoid92*) for the area of Poland was computed in the Department of Planetary Geodesy, Space Research Center in Warsaw in 1993 (Łyszkowicz 1993). This gravimetric geoid model was computed using collocation-integral method and based on OSU81 geopotential model to degree and order 80 and on about 6 000 mean gravity anomalies from the area of Poland. The evaluation of accuracy of this model indicate that the mean square error is ± 26 cm.

Within last 30 years author computed number of more and more exact gravimetric geoid models for the area of Poland. The way of calculation, data used to calculations and method of accuracy estimation of these models is given in Łyszkowicz (2010). From fig. 12 result that the accuracy of gravimetric geoid models during the last 30 years increase five times.

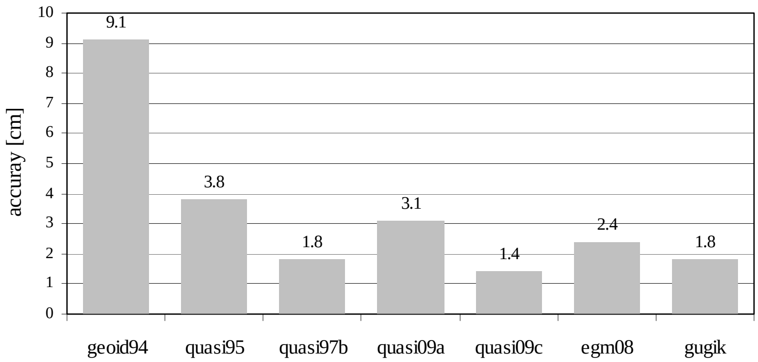



Fig. 12. Accuracy of N from the successive gravimetric models (after fitting)

In order to assess the possibility of uses of “GPS levelling” in the field the estimation of accuracy of individual components in the formulae (6-1) and (6-2) was done.

From the evaluation results appears that the ellipsoidal height is determined, in the case of absolute measurements, with comparatively big errors order 10-30 m. Also with big error order tens of decimeter the height *H* referred to the mean sea level is measured. This type of “GPS levelling” can be use in air and at sea navigation only in the case "open space" of the air and water. Absolute GPS measurements do not find the use in geodetic works.

However in the case of static relative GPS surveys and by assuming the option of precise GPS measurements one should expected that “GPS levelling” should give better or approximate results than classic levelling (Table 3 and 4). Because this scenario requires static GPS measurements and the use of two receiver then the advanced elaborating of results, so it is not very competitive in comparison to classic height measurements.

Height differences determined from differential GPS measurements (DGPS) and using well-known geoid ellipsoid separation, can be used in the so-called geographic information systems (GIS), while height differences determined from GPS measurements in the real time (RTK) and with use well-known geoid distances from the ellipsoid have application in the land information systems (LIS).

Table 3

Mean square errors of “GPS levelling”, in millimeters, optimistic option

| | 1 km | 10 km | 50 km | 100 km |
|---|---|---|---|---|
| GPS, precise measurements | 0.3 | 3 | 15 | 30 |
| geoid | 0.1 | 1 | 5 | 10 |
| "GPS levelling" | 0.3 | 3.2 | 15.8 | 31.6 |

Table 4

Mean square errors of “GPS levelling”, in millimeters, realistic option

| | 1 km | 10 km | 50 km | 100 km |
|---|---|---|---|---|
| GPS, engineering survey | 15 | 150 | 750 | 1500 |
| geoid | 1 | 10 | 50 | 100 |
| "GPS levelling" | 15 | 150 | 751 | 1503 |

## 7. Conclusions

Quickly developing technologies have the largest influence on maps creation in digital form and on development of the geographic information systems. This causes that field and office works are strongly integrated, and therefore the costs of map production decrease and the efficiency of the surveying works increased.

To mention technologies one can include the wide use of computers, thanks to which the possibility of collection, processing, analyzing and visualization the geodata in the short time.

Significant influence on the development of the GIS technology also has the development of GPS, and first of all improvement of accuracy, enlargement of the accessibility of receivers (through the costs reduction) and reduce their sizes (what make easier field measurements) and making possible co-work of the receivers with additional modules. Additionally comes common use of Internet and wireless connections, thanks to this GIS becomes mobile because exists the possibility of sending data between various platforms in the real time.

First time in the history of geodesy was realized global geocentric reference the ITRF about unparalleled so far accuracy, enabling measurement of the global and regional changes of the earth and their modeling in time and space. Computed recently, very precise geopotential model EGM08 gives the possibility of creation of the global vertical reference system.

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