People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

Larbi Ben M'hidi University of Oum El Bouaghi

Faculty of Earth Sciences and Architecture

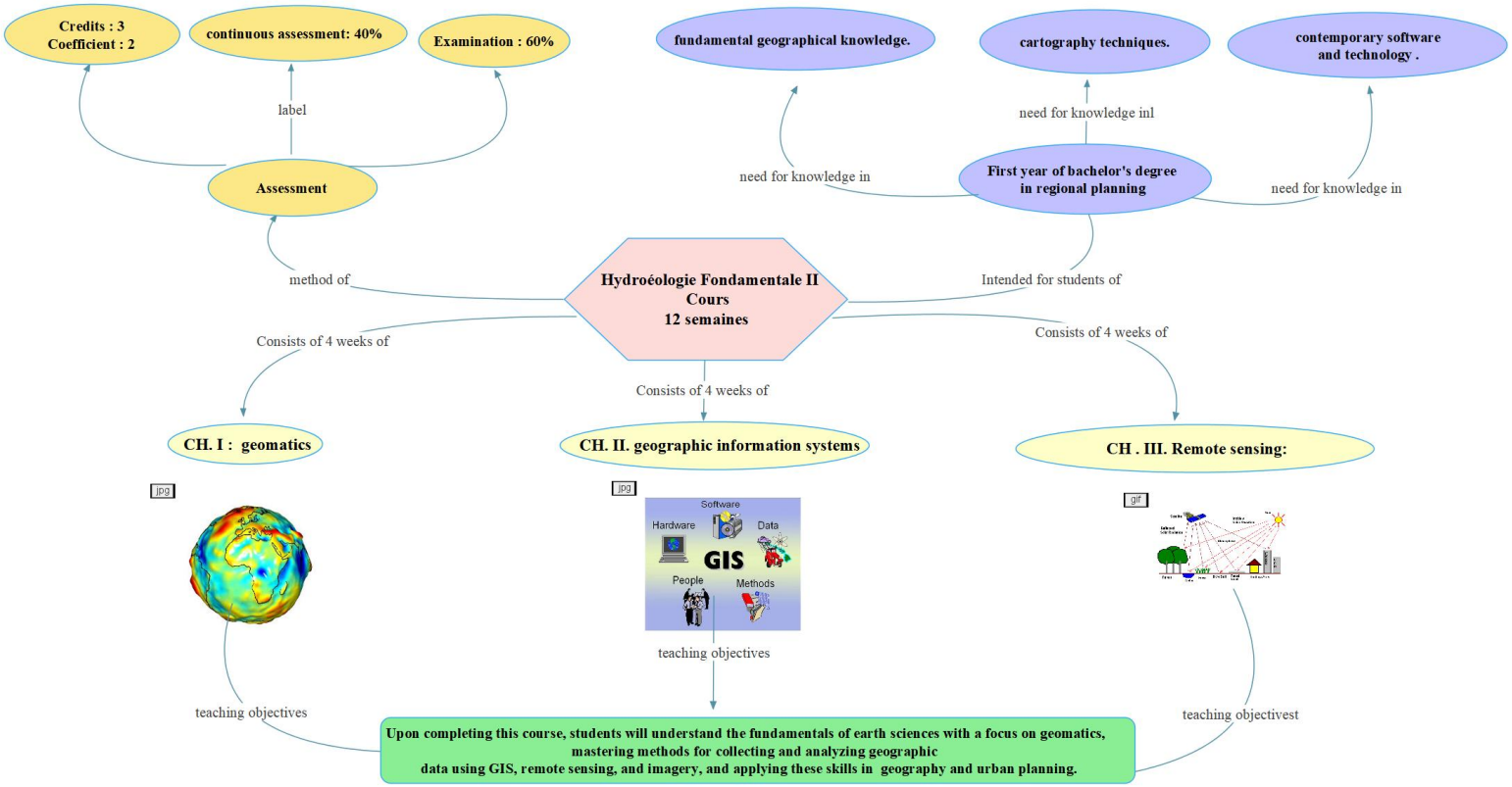
Department of Geography and Urban Planning

Module: Introduction to Geomatics

First Year Bachelor's Degree

Presented by: **Leila Boulaksa**

Academic year : 2024-2025



References:
Gomarasca, M. A. (2009). *Basics of geomatics.* Springer Science & Business Media. doi:10.1007/978-1-4020-9014-1
Rockville. M. (1977). *Basic Geodesy.*
Rocha, J. &. (2019). *Geographic information systems and science. IntechOpen.*
G Inst. Biruk. (2020). Introduction to Remote Sensing.

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Teaching unit : Methodology course UEM21

Title of subject M 213: Introduction to geomatics

Credits : 3

Coefficient : 2

1 geomatics

-Definition of concepts

Disciplines of geomatics:(Cartography, Geographic Information Systems (GIS), Computing, Aerial and spatial imagery, Geodesy, Topometry, Remote sensing Photogrammetry, Mathematics)

Application of geomatics

2- geographic information system:

-GIS components (hardware, software, data, users, etc.)

-Geographic database

-GIS components (geoprocessing, geovisualisation, geodatabase)

- Fields of application of GIS

- Advantages of using GIS

3- Remote sensing:

-Operating principles

-Electromagnetic radiation

-Satellites

-Multispectral signatures

-Resolution

-Fields of application of remote sensing

-Advantages of using remote sensing.

Assessment method: Examination and continuous assessment

Unité d'enseignement : UE Méthodologique UEM21

Intitulé de la matière M 213 : introduction à la géomatique

Credits: 3

Coefficient: 2

the general objectives of the course.

Upon completion of this course, students will have developed an understanding of the fundamentals of specific earth sciences, with a focus on geomatics and its applications across diverse disciplines. They will acquire knowledge of methodologies for collecting and analyzing geographic data, including geographic information systems, aerial and satellite imagery, and remote sensing. Additionally, they will learn to employ these techniques in research and practical applications, with a particular emphasis on geographical studies and urban planning.

Prerequisites:

It is imperative that the individual possesses fundamental geographical knowledge.

It is imperative that students possess fundamental knowledge of computer technology and the utilization of computers.

It is imperative to have a fundamental understanding of mathematics and statistics, as these disciplines are instrumental in analyzing geographical data.

It is imperative that students possess a comprehensive understanding of cartography techniques.

The capacity to analyze, interpret, and draw conclusions is imperative for comprehending and applying geomatics concepts.

The ability to work with contemporary software and technology is essential.

While these prerequisites are not mandatory, they have been shown to facilitate students' comprehension and assimilation of the course's concepts.

Assessment method: The assessment comprises 40% tutorial work and 60% examination.

The possession of the ability to work with contemporary software and technology is essential.

While these prerequisites are not mandatory, they may facilitate students' comprehension and assimilation of the course's concepts.

Assessment method: 40% tutorial work + 60% exam.

Chapter I: Geomatics

What is Geomatics?

Geomatics represents the merging and overlap of the fields of surveying, mapping, remote sensing science, and information science": (Li. D. Shen. X. & Wang. L., 2018)

The term "geomatics" comes from the French word "géomatique," which can be a noun (la géomatique), an adjective (e.g., projet géomatique), a verb (géomatiser), a process (géomatisation), or a profession (géomaticien). The term combines "geo," meaning Earth, with "informatics," formed from "information" and "automation" with the suffix "-ics," which is commonly used to denote scientific fields. **(Bédard, 2008**)

From a historical standpoint, the term "geomatics" first appeared in France in the early 1970s within the Ministry of Equipment and Housing, as noted by the Permanent Commission on Geomatics. Initially, geomatics encompassed only computer-assisted mapping activities, similar to "photo geomatics," a term coined around the same time for computer-assisted photogrammetry. However, these terms did not gain widespread acceptance due to their narrow scope and failure to introduce enriched concepts. **(BÈDARD, 2007)**

Several years later, "geomatics" resurfaced in Quebec City, Canada, without its creators being aware of its prior usage in France. Despite its French origins, this time the term gained global traction because it was crafted to convey a novel concept that reflects the modern perspective of surveyors,

photogrammetrists, geodesists, hydrographers, and cartographers. **(BÈDARD, 2007)**.

Geomatics is a discipline that combines practices, methods, and technologies for collecting, analyzing, and disseminating geographic data. Its ultimate goal is to provide a spatial representation of collected data to identify, visualize, and demonstrate the results of statistical analyses. In doing so, geomatics adds a new dimension of analysis to your data, which was previously only analyzed in two dimensions. **(ESRI, 2024)**

The term "geomatics" is a logical contraction of the words "geography" and "informatics." It thus allows us to harness the strengths of both these fields. **(ESRI, 2024).**

2- Disciplines of geomatics:

The disciplines and techniques constituting geomatics are:

• ***Computer science*:** "the study and application of languages and methods for making precise and understandable descriptions of things." **(Long.Timothy. et al, 1998)** , it uses in geomatics to represent and process applicable information through the development of technological instruments (i.e., hardware) and of methods, models and systems (i.e., software). **(Gomarasca, 2009)**

• ***Geodesy*:** Although geodesy is the oldest among earth sciences, dating

Back to the Sumerians of 5000 years ago, its subject and even its name have been widely unknown. **(Rockville. M., 1977)** According to Friedrich Robert Helmert (1880), the definition of geodesy is: "geodesy (γη = Earth, δαιω = I divide) is the science of the measurement and mapping of the Earth's surface." **(Torge. W. & Müller. J, 2012)** Therefore, geodesy aims to determine the Earth's shape and size. It defines two key references: the geoid, representing Earth's complete form, and

the ellipsoid, a simplified mathematical model. Additionally, geodesy studies the Earth's external gravitational field and its variations over time. **(Gomarasca, 2009).**

***Topography*:** It began as part of geodesy and has since evolved into a combination of procedures for direct land surveying. Topography uses methods and instruments to accurately measure and depict the Earth's surface. **(Gomarasca, 2009).**

• *planimetry*: " to determine the relative positions of the representation of points on the Earth's surface with respect to the same reference surface" (Gomarasca, 2009).

• *altimetry*: "to determine the height of the points on the Earth's surface with respect to the geoid surface"; (Gomarasca, 2009).

• *tachymetry*: "for the planimetric and altimetric survey of the Earth's surface zones" (Gomarasca, 2009).

• *land surveying*: "to measure areas, moving and rectify borders, leveling zones of the Earth's physical surface.

• *Cartography*: " to supply a possible description of the shape and dimension of the Earth and its natural and artificial details, by means of graphical or numerical representation of more or less wide areas, following fixed rules".

• *Photogrammetry*: Photogrammetry is a technique that emerged shortly after the invention of photography in the 19th century. Even before that, artists such as Brunelleschi and Albrecht Dürer had explored perspective using simple optical tools. Their goal was to reproduce images on paper that were as neutral, objective, and faithful to reality as possible. (Kalantari. M. & Kasser, 2008)

A widely accepted definition of photogrammetry describes it as the art, science, and technology of obtaining accurate information about physical objects and the environment. This is achieved through the collection, measurement, and interpretation of images—whether photographic or digital—and the creation of analog or digital models based on electromagnetic energy captured by survey systems like cameras or scanners, all without direct contact with the objects. Photogrammetry is primarily (Gomarasca, 2009) used to determine the positions and shapes of objects by measuring them on photographic images.

• ***Remote Sensing*:** to remotely acquire territorial and environmental data and to combine methods and techniques for subsequent processing and interpretation (this definition also fits digital photogrammetry)

• ***Global Positioning System (GPS)*:** "to provide the three-dimensional (3D) position of fixed or moving objects, in space and time, all over the Earth's surface, under any meteorological conditions and in real time". (Gomarasca, 2009)

• ***Laser scanning system*:** "to locate objects and measure their distance by means of the incident radiation in the optical frequencies (0.3–15 μm) of the electromagnetic spectrum". (Gomarasca, 2009)

• ***Geographical Information System* (GIS):** " to make use of a powerful combination of instruments capable of receiving, recording, recalling, transforming, representing and processing georeferenced spatial data".

• ***Expert System (ES)*:** to consider instruments capable of imitating the experts' cognitive processes and their ability to manage the complexity of reality by means of interdependent processes of abstraction, generalization and approximation". (Gomarasca, 2009)

• ***WebGIS*:** "to distribute geographic data remotely stored on dedicated machines for databases, according to complex network architectures. "

• ***Ontology*:** The term ontology is borrowed from philosophy, where it means a systematic account of Existence. For AI systems, what “exists” is that which can be represented. (Gruber, 1995) It is used in geomatics to specify a conceptualization, i.e., the description of concepts and relationships that exist for an element or among various elements of a group, entity, or class; conceptualization is an abstract, simplified vision of the world to be represented for a given application. (Gomarasca, 2009).

Geodesy and cartography

Geodesy is a fundamental science with mathematical and physical foundations. Its applications extend across various branches of knowledge, such as topography, cartography, photogrammetry, and navigation. It is closely related to astronomy and geophysics, with these disciplines often relying on each other's methods and objectives. (Gomarasca, 2009)

The most important objective of geodesy is the study and determination of the Earth's shape and dimensions. Since this objective is closely linked to determining the positions of points on Earth's surface (georeferencing), the practical implications of this science will be of particular interest to us.

What is geodesy? (Navarro, 2011)

Geodesy is one of the Earth Sciences; according to Helmert (1880), it can be defined as the science that studies the shape and dimensions of the Earth.

Despite being the oldest of the Earth Sciences, geodesy is less well-known compared to other familiar Earth Sciences such as geography, geology, and geomorphology, etc. (Rockville. M., Basic Geodesy., 1977).

Shape and size of the Earth

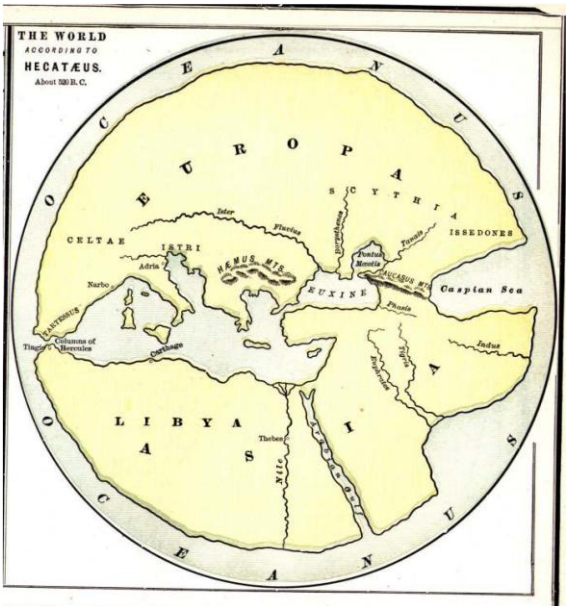
The study of the Earth's shape is an ancient topic that dates back to antiquity. In the West, it is believed that interest in the Earth's shape began in ancient Greece, around 600 BC. Since then, many models of the Earth's shape have been proposed. However, our historical knowledge in this field is very limited, as only a few documents from that era have survived.

Initially, Thales (624–546 BC) proposed that the Earth was a flat disk floating on an infinite ocean. He based his theory on the idea of the 'oikoumene,' which denoted the world encompassing all the lands known to navigators and conquerors.

While his contemporaries, Anaximander (610 – 546 BC) and Anaximenes (585 – 528 BC), proposed a model suggesting that the Earth was a cylinder floating on a limited ocean, resembling a slice of a column with a diameter three times longer than its height, and on its upper flat face is the world modeled on the map, with this whole structure suspended in space.



(pic nº01): **floating cylinder Earth model**

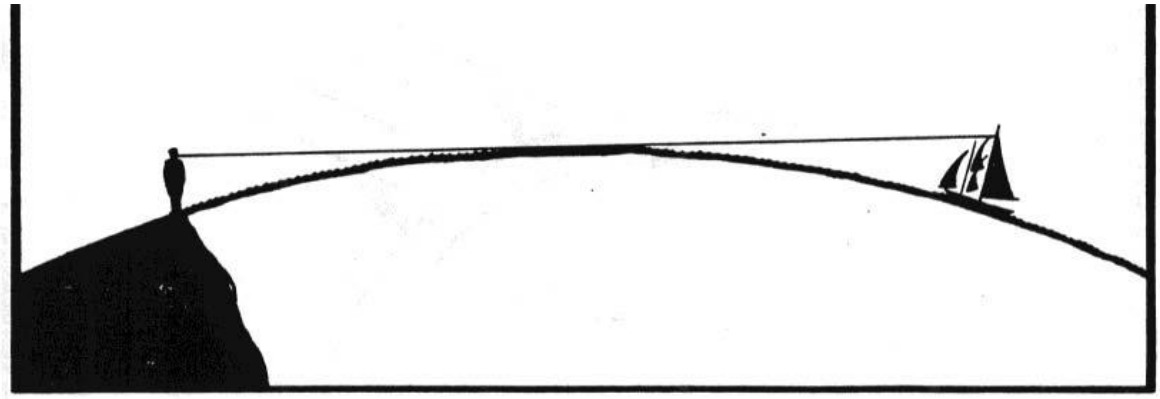


(pic nº02): floating disk Earth model

Source : (Panou. E. Kalachanis. K. & Dimitrijevic. M. S., 2020)

The spherical Earth model

Pythagoras (570 to 480 BC) was one of the early scientists interested in studying the shape of the Earth. He is considered the first to propose a spherical Earth, which finally allowed for an explanation of ships disappearing from view when they reach the horizon. Pythagoras not only proposed a model of the Earth but also developed a system of the universe, along with a group of scientists (mathematicians, philosophers, politicians, and religious figures) belonging to the Pythagorean school (500 to 200 BC). This system is based on the concept that the cosmos revolves around the spherical Earth, which rotates on its axis, while the planets (Mercury, Venus, Mars, Jupiter, Saturn), the Sun, and the Moon orbit the Earth. As for the stars, they are situated even further on the celestial sphere.

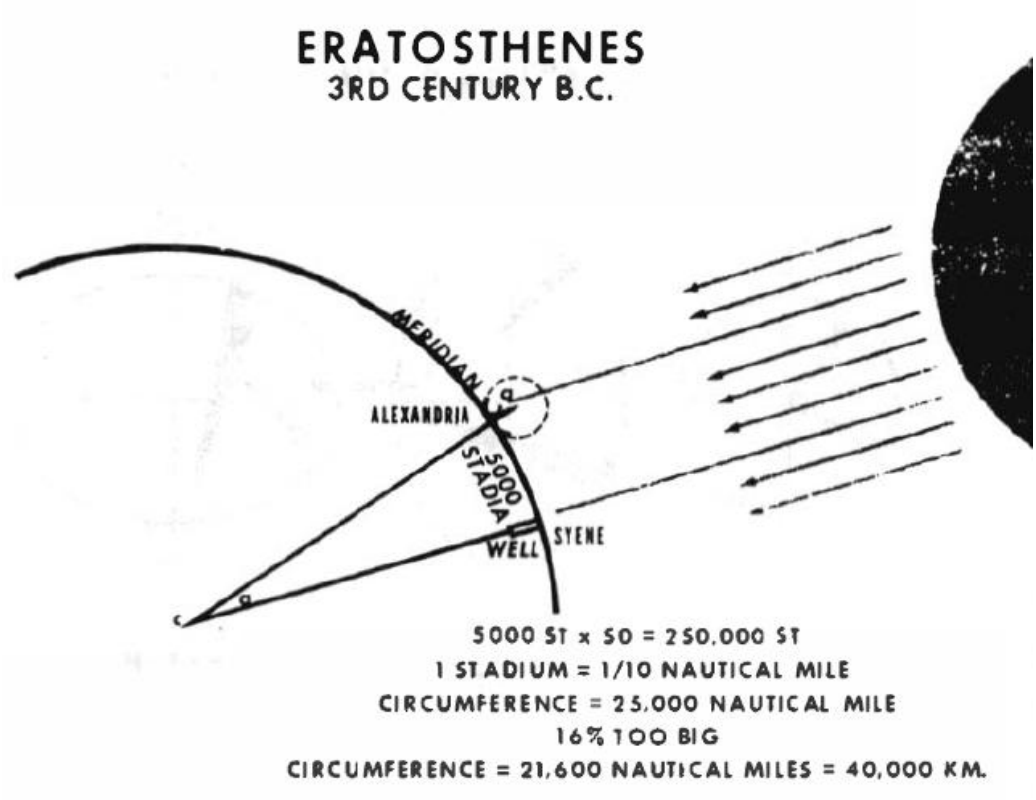


(pic nº03): ships disappearing from view when they reach the horizon
Source: (Rockville. M., 1977)

Earth size

Aristotle (384 to 322 BC) and Archimedes (287 to 212 BC) are credited with estimates of the Earth's circumference between 400,000 and 300,000 stadia, but no account of measurement techniques has reached us.

Eratosthenes (284 to 192 BC) gives a relatively precise value for the Earth's circumference (250,000 stadia, estimated at between 40,000 km and 50,000 km, based on estimates of the stadia unit). An almost complete description of the method used has reached us.

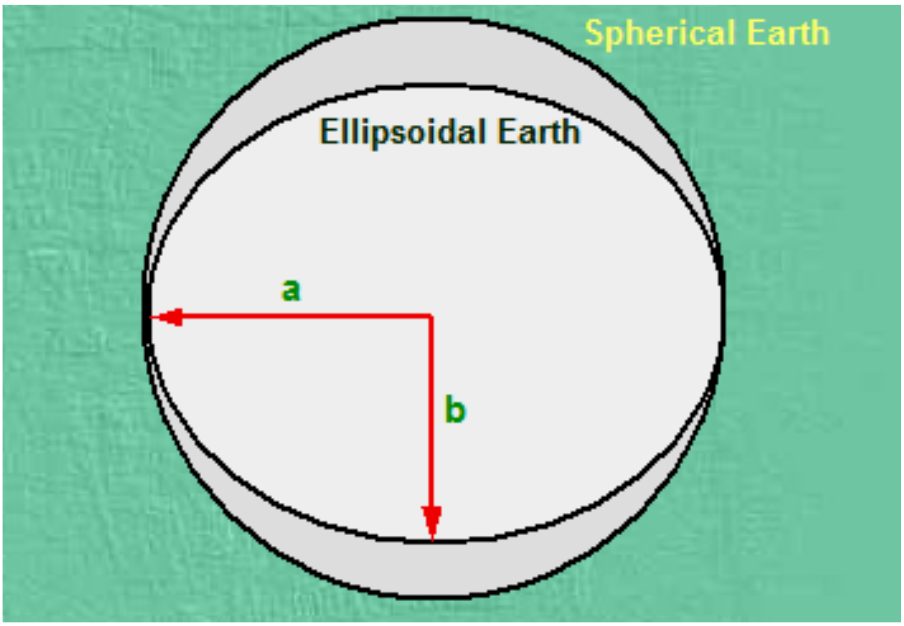


(pic nº04): earth's circumference measurement of Eratosthenes (Rockville. M., 1977)

The Ellipsoid Earth

At the end of the 17th and beginning of the 18th century, the geographers Picard and Cassini used triangulation for the first time to measure the entire French territory. Cassini noted that an arc of the meridian measured in the North of France was slightly smaller than an arc measured in the South. This discrepancy was due to measurement imprecision, but Cassini deduced that the Earth had an ovoid shape, that is, it was elongated at the poles. Based on the work of Newton and Huygens, English scientists contested this hypothesis, asserting, on the contrary, that, for physical reasons (centrifugal force), the Earth must be flattened at the poles. A dispute ensued between French and English scholars. In order to put an end to the dispute, the French Academy of Sciences sent two expeditions in 1735 to Peru and Lapland to measure meridian arcs there. The measurements that were carried out led to the conclusion that the Earth was flattened at the poles.

In this hypothesis, the Earth is an ellipsoid, that is to say that a section of the Earth passing through the poles has the shape of an ellipse.



(pic n°05): The Ellipsoid Earth

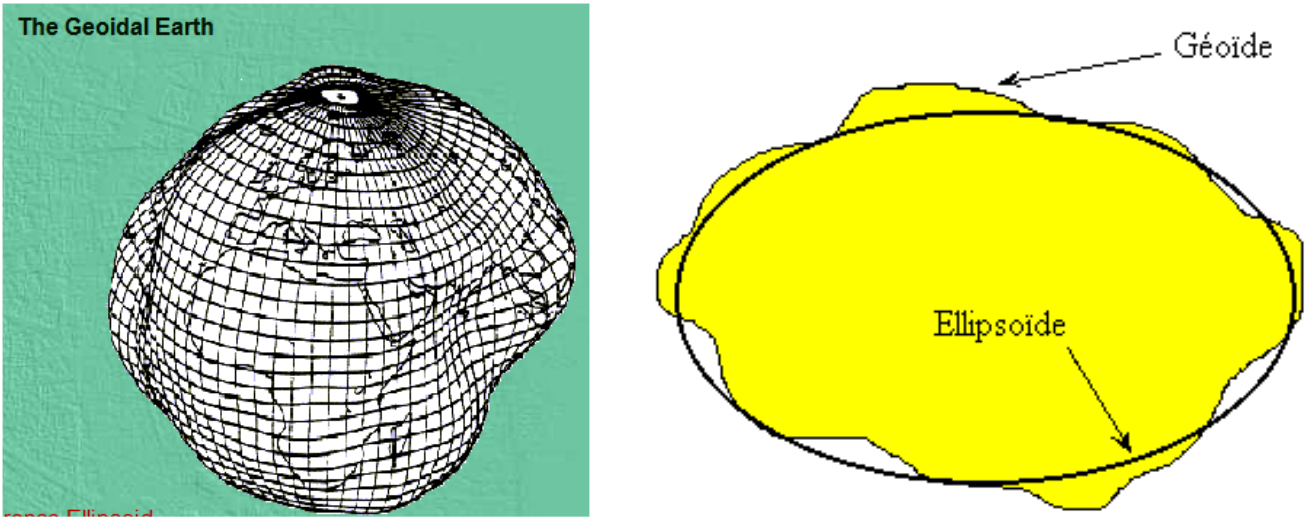
Source: https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcR-WEUuR5prl7ZGgMrNtJpzUHSX34sRFSWOtQ&s

Actually, things are quite complicated. When we talk about a pear shape or an ellipsoid, we obviously don't mean the shape produced by mountains and valleys—the topography. Since we can measure elevations above sea level, as recorded on topographic maps, we can disregard them and examine the shape of what remains: the sea-level surface itself, extended from the shoreline into the land without the elevations above it. This sea-level surface is also called the geoid. The shape of the geoid is what we mean by the figure of the Earth.

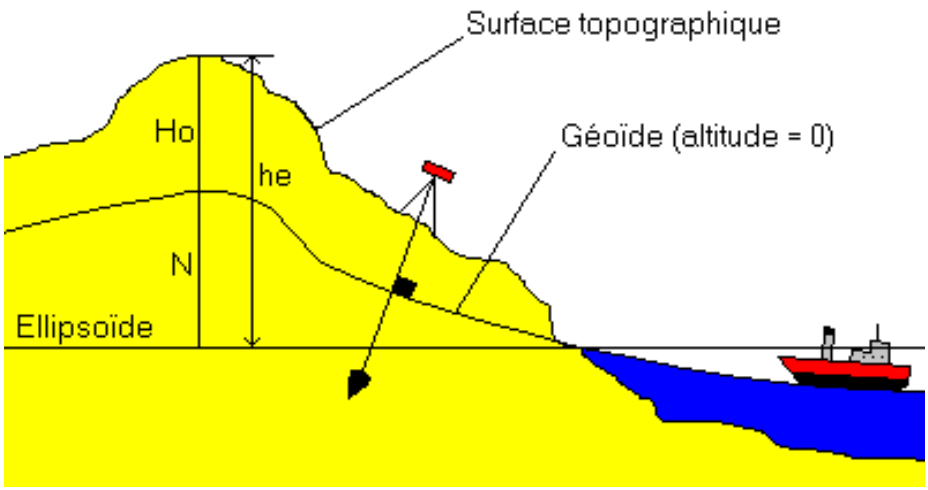
The Geoidal Earth

Following the work of 18th-century English and French geographers, the mean sea level was approximated by an ellipsoid, on which major cartographic works were based. However, cartographers noted anomalies in certain places. Near large mountain ranges, the triangulations closed poorly, as if the plumb line had abnormal deviations. Thus, the surveyor Méchain, charged by the Convention with measuring an arc of the Meridian between Dunkirk and Barcelona in order to define the meter, noted a triangulation error at the level of the Pyrenees. He persisted in redoing his measurements and calculations, and died in Spain without being able to determine the cause of the error.

In fact, mountain masses, by simple gravity, cause the plumb line or level to deviate, thus creating the phenomenon of "vertical deviation". It was then discovered that the Earth's mantle's lack of homogeneity, creating localized mass concentrations, causes a similar phenomenon. This is how surveyors and cartographers discovered, with horror, that the Earth did not have the elegant contours of an ellipsoid but had an irregular, chaotic shape and, above all, was not mathematically modellable.



(pic n°06-07-08): The geoidal Earth



Thus, we distinguish three surfaces: the topography, the geoid, and the ellipsoid. Topographic maps give the elevations above sea level (the geoid). Geoidal maps show geoidal heights relative to the ellipsoid. Together, they give the total height of the topography above the ellipsoid at any point.

Chapter II: Geographic information systems: (GIS)

"The importance of knowing where something happens. Knowing where something occurs is vital if we want to go there, or if we want to send someone there, or if we want to find some other information near the same place, or simply, for example, if we want to inform about the people living in the surroundings."

The importance of "where" stems from the rapid growth and parallel evolution and development of new technologies, which increasingly have a significant presence in our daily lives. For example, we have great availability of GIS on the Internet, as well as extensive local connection networks that allow us to access information quickly. (Lloret, 2009).

1. **What is GIS?**

The concepts of Geographic Information Systems (GIS) have varied and changed over time and across different disciplines. Below are some of these definitions.

Burrough (1986) was the first to define GIS as a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data from the real world. Cowen (1988) defined a GIS as a decision-support system that integrates referenced spatial data within a problem-solving environment. (Gomarasca, 2009)

A geographic information system is "A system of hardware, software, data, people, organizations, and institutional arrangements for the collection, storage, analysis, and distribution of Earth territory information. (Lloret, 2009)

Aronoff (1989) defined a GIS as a manual or computer-based set of procedures for storing and manipulating geographically referenced data. (Gomarasca, 2009).

Burrough (1997) redefined GIS as a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data from the real world for specific purposes. (Gomarasca, 2009)

2. Why do we use GIS?

The fundamental differences between paper cartography and digital cartography are:

- While paper cartography has a static character, digital cartography is dynamic in the sense that its updating is much simpler, both from a technological and economic point of view.
- The information must be perfectly structured and unambiguous for programs to interpret it. Computers cannot deduce information that has been eliminated or modified by the generalization processes used. A common example is contouring lines cut to insert a text label.
- The concept of a **layer** is introduced as a file, or part of a file, that contains spatial information for a single variable (in some cases, a file can store multiple layers). The term **map** is reserved for a combination of layers prepared for visualization or printing. Information of different types should not be mixed in the same layer. (Sarría, 2006)

3. Is GIS a Science?

In 1992, Goodchild was invited to write a paper defining Geographic Information Science (GIScience). By that time, GIS had been widely adopted by industry and research and had also become popular in educational programs. Consequently, the GIS community began to view GIS as more than just a tool or system, turning their attention to the study of GIS itself.

Goodchild's paper made a significant contribution by coining the term "Geographic Information Science" (GIScience or GISc). However, he did not provide a formal definition of the science. Instead, he emphasized the unique characteristics of geographic data and the necessity of specialized methodologies to handle it. Goodchild outlined eight key areas on which this emerging science should focus:

- Information gathering and quantification
- Data acquisition
- Geospatial statistics and location analysis tools
- Spatiotemporal modelling and spatial concepts
- Spatial data infrastructures, algorithms, and procedures
- Visualization
- Decision-making, along with administrative and ethical considerations

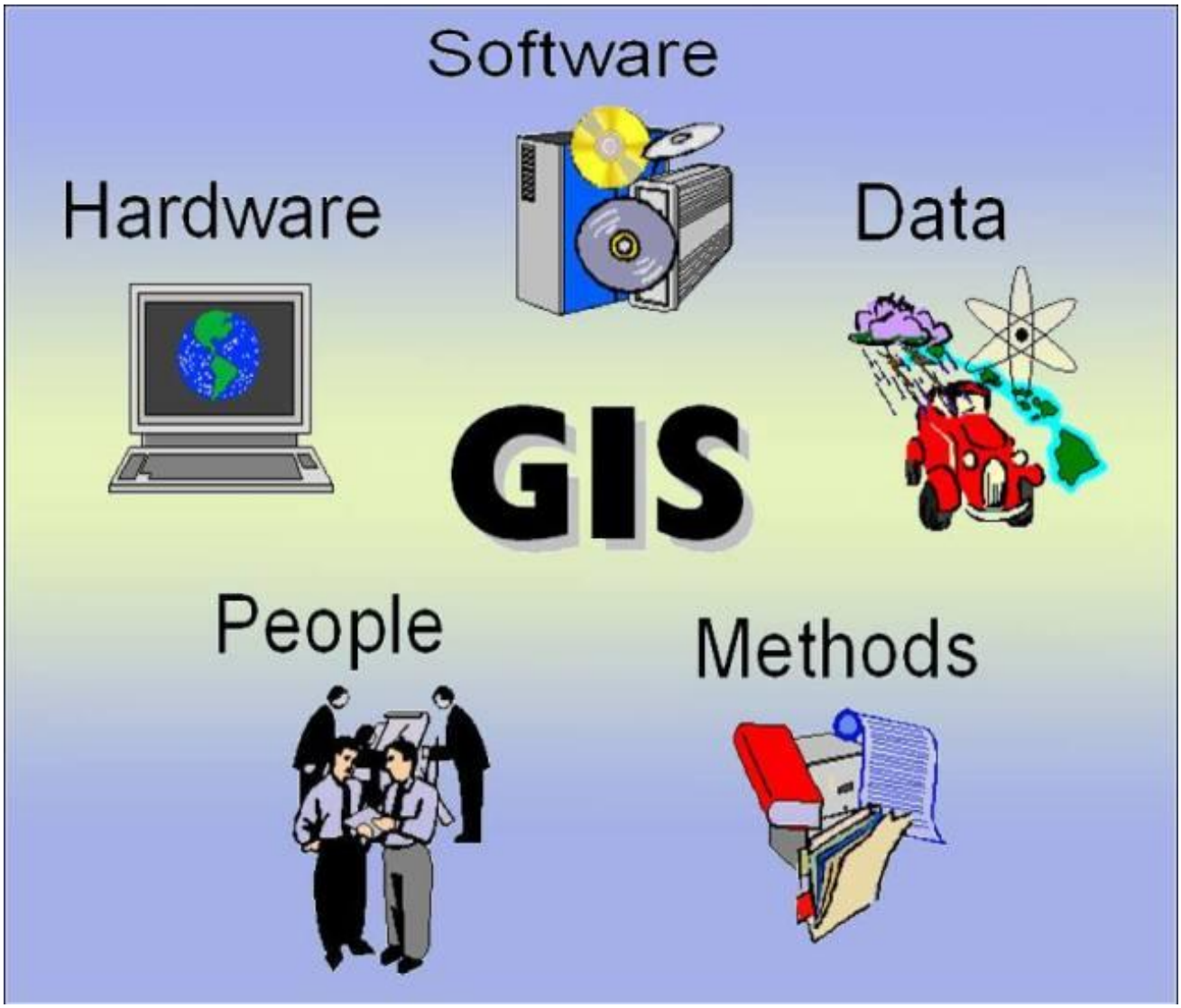
Nearly 30 years have passed since Goodchild published his seminal paper, Geographic Information Science, yet it is noteworthy that:

The topics he identified remain highly relevant today. For example, challenges in data collection and measurement, such as generalization and abstraction, persist. Modern data capture faces new issues related to the massive influx of data driven by web and Internet of Things (IoT) technologies, as well as concerns about data quality in an era where nearly anyone can generate geographic data. Visualization has evolved from 2.5D and 3D representations to 4D and 5D, virtual reality, and immersive environments. Meanwhile, institutional, managerial, and ethical challenges have grown alongside the rise of open data and software interoperability. (Rocha, 2019)

4. Components of a GIS

To establish an effective organizational structure, it is essential to clearly define the components of a GIS, its organizational framework, and the processing logic that shapes its structure (Gomarasca, 2009). A GIS consists of the following components:

- Hardware or equipment
- Software or programs
- Data
- The human factor or liveware
- Methods or procedures



(pic nº 09): Components of a GIS

Source: (https://gisuop.wordpress.com/2014/07/02/component-of-gis/ , 2025)

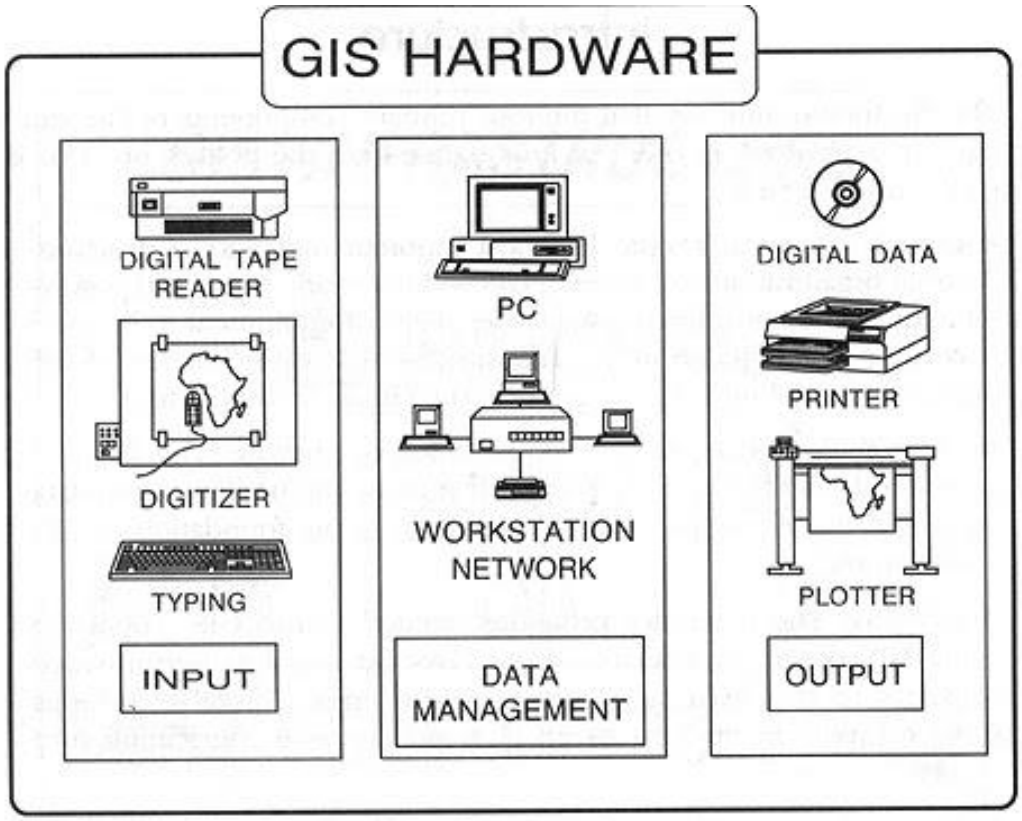
4.1. Hardware or equipment

With advances in technology, access to high-capacity computing hardware for geospatial data processing is increasing.

The equipment necessary for data and information input and output, as well as for representing cartographic products, consists of personal computers that host

the system, workstations, and specialized peripheral accessories (keyboards, printers, plotters, large-format scanners, monitors, mice, etc.) (Araque Rojas, 2014).

The computer's performance significantly affects the efficiency of the software tools and peripherals used for data input (Gomarasca, 2009). (pic nº)



(pic nº 10): GIS Hardware

Source: (http://geoinfo.amu.edu.pl/wpk/rst/rst/sect15/sect15_7.html , 2025)

4.2. Software or programs:

It is the component responsible for providing the user with the necessary functions for capturing, storing, analyzing, and displaying geographic information.

In recent years, GIS software has advanced rapidly, evolving from command-based systems to menu-driven systems that are easier to use and require less training. (Araque Rojas, 2014)

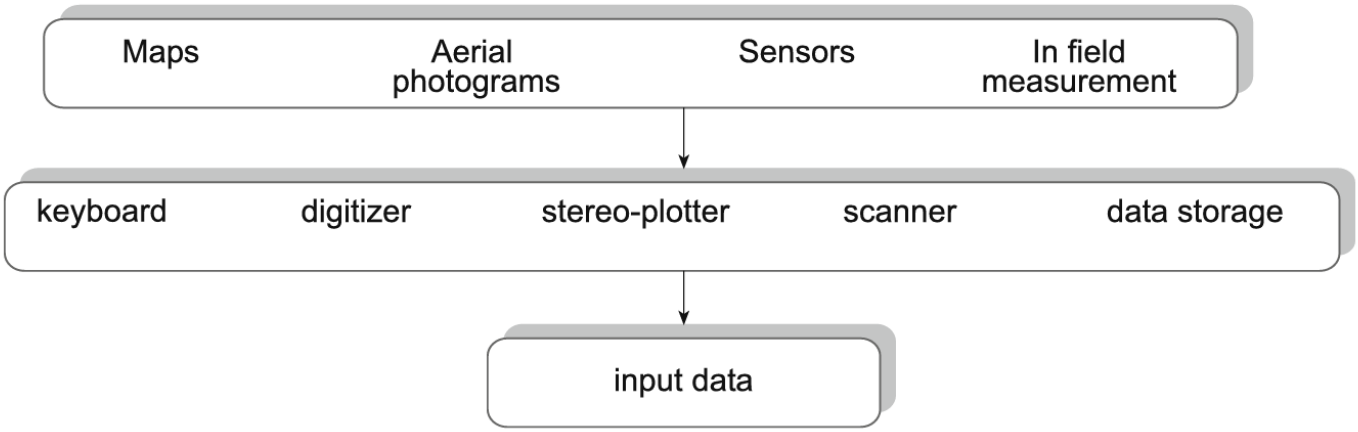
A GIS must contain the following main software components:

- the Database Management System (DBMS);

The basic functions, managed through an appropriate user interface, are dedicated to: (Gomarasca, 2009)

•data input and validation: Geographic data can be entered through manual or automatic digitization and/or updating of spatial information and its descriptors. (Araque Rojas, 2014)

•data storage and database management; (Gomarasca, 2009)



(Gomarasca, 2009)

(pic nº 11): data storage and database management

•Data Processing and Analysis: This refers to the processing, analysis, and applications performed with geospatial data. For this, there must be functions for:

- Updating, detecting, and correcting errors in the data.

- Analyzing and responding to user queries.
- Typical operations such as overlaying geographic layers, statistics, cartographic changes, calculating measurements (distances and areas), and generating analysis reports.

- Output and Presentation of Data and Information: This is how the final GIS product is presented to the end user in a graphical and visual manner, and can be in formats such as:
  - Physical or analog: maps, images, graphics, report tables; printed on plotters or printers.
  - Digital: viewed on a computer monitor; for example, digital maps, satellite images, databases, etc. (Araque Rojas, 2014).

4.3. **DATA:**

Data are a critical component of any geographic information system (GIS). (Gomarasca, 2009). They are among the most important components because reliable, accurate information directly impacts the system's quality. (Araque Rojas, 2014) because the quality of all generated outputs relies heavily on the availability, accuracy, and consistency of the data. This data (Gomarasca, 2009) can be obtained through:

- Own resources digitized or scanned.
- Databases.
- In-field checks or verification and topographic surveys.
- Satellite images, aerial photographs, and digital cartography are also important sources of data. (Araque Rojas, 2014).

4.3.1. **Data model in GIS:**

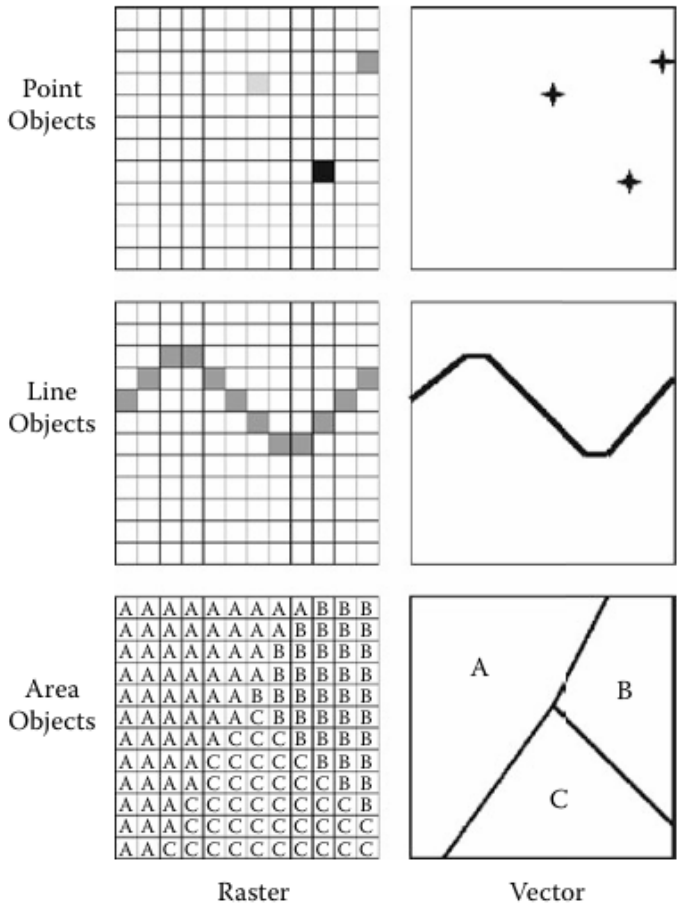
A data model establishes a set of rules for identifying and representing real-world features, known as entities, as spatial objects within a digital system. These

spatial objects are defined by their attributes and geometry. Attributes are organized according to thematic or semantic categories, and geometry is described using geometric and topological structures.

In this context, data fall into two main categories: spatial and attribute.

4.3.1.1.**Spatial data**: refers to the geographic locations of features, such as the latitude and longitude coordinates of dams, monitoring stations, and similar sites. Spatial data are typically represented as geometric objects—points, lines, or polygons—each corresponding to a different type of feature. For example, a well is represented as a point, a river as a line, and a watershed boundary as a polygon. Spatial data can also take the form of continuous fields or images, such as those produced by satellite sensors.

To visualize natural phenomena, one must first determine the best way to represent geographic space. Data models are sets of rules and/or constructs that describe and represent aspects of the real world in a computer. There are two primary types of data models available for this task: raster and vector. (Campbell, 2012)

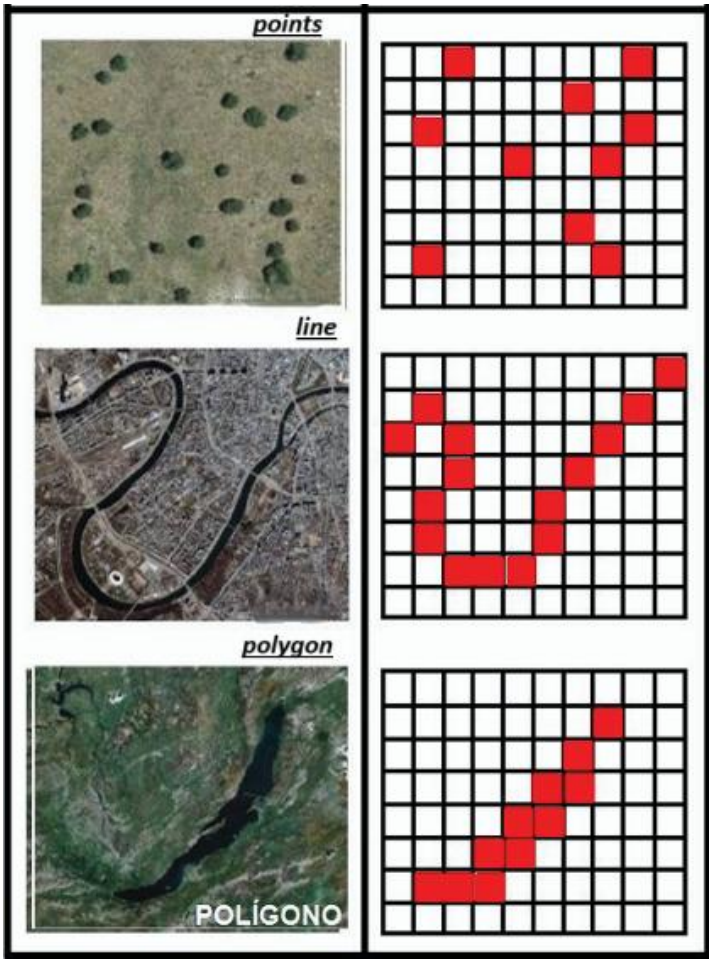


(Johnson, 2009)

(pic nº 12): Data representation model in GIS

- The raster, or field, model is one of the primary ways to represent the world in geographic data and spatial features. In this approach, the area of interest is divided into a regular grid of cells—often called pixels—where each cell contains a value representing the data at that location. (Johnson, 2009), where point features are represented by single cells, line features by sequences of neighboring cells, and polygon features by collections of contiguous cells. The cell value corresponds to the attribute of the spatial feature at the cell location. Raster data is well suited to continuous features, including elevation and precipitation. (Chang, 2019)

This type of uniform grid is known as a raster data structure. Raster models are particularly well-suited for depicting variables that change continuously across space, such as temperature, rainfall, or elevation. Within a raster, a point is characterized by a unique identifier, its grid coordinates (i, j), and its associated attribute value. Similarly, a line is described by a line identifier, a sequence of coordinates that trace its path, and its attributes. An area segment in a raster is defined by an area identifier, a set of coordinates that outline its boundaries, and its attributes. (Johnson, 2009).



From: (Araque Rojas, 2014)

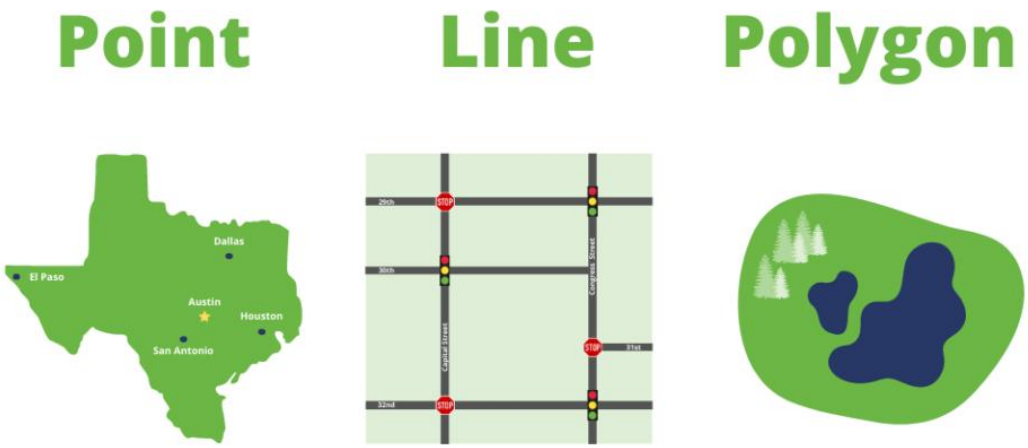
(pic nº 13): Real-world feature representation in Raster format

5. The vector data structure represents spatial features differently: regions are depicted as polygons, lines as polylines, and points as discrete locations. The vector model is commonly used to map features such as river networks, pipelines, and infrastructure like fire hydrants. These data sources often originate from land surveys, computer-aided design (CAD) drawings, or processed imagery. A distinguishing feature of the vector model is its use of topology, which defines how spatial features are connected or related to one another. In this context, a

point's geometry is specified by its two-dimensional (x, y) coordinates, while sequences of such coordinates describe lines, strings, and areas. (Johnson, 2009)

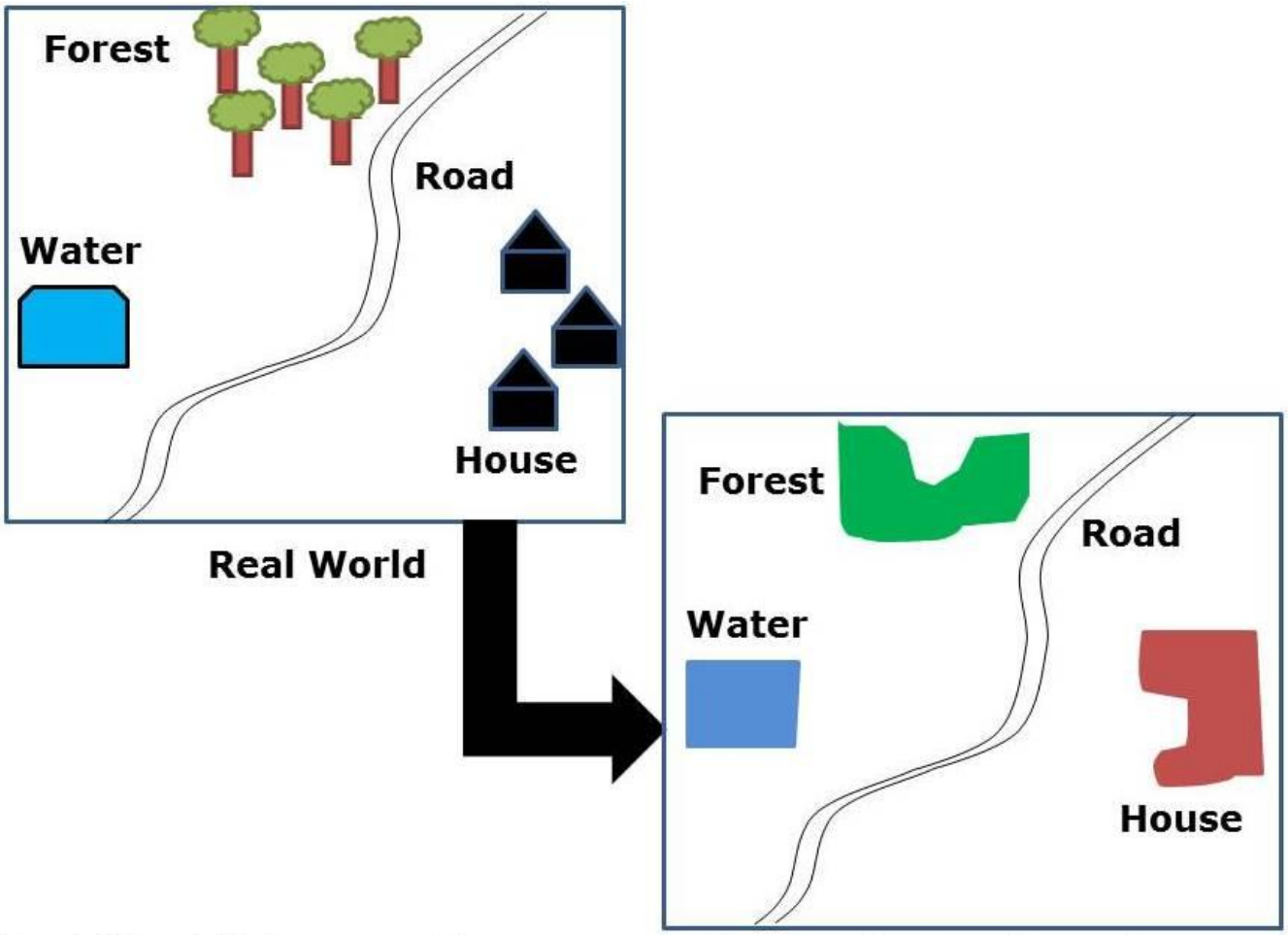
Key elements of the vector model include:

- **Node:** The intersection point of multiple lines or strings, or the start/end point of an arc, identified by a unique node number.
- **Arc:** A line or string with a specific arc number, defined by its start and end node numbers, and the polygons it borders on either side.
- **Polygon:** An area identified by a polygon number, formed by a series of connected arcs arranged with a specific direction (such as clockwise).



From: https://guides.lib.uconn.edu/c.php?g=1409975&p=10500444

(pic n°14): data representation forms



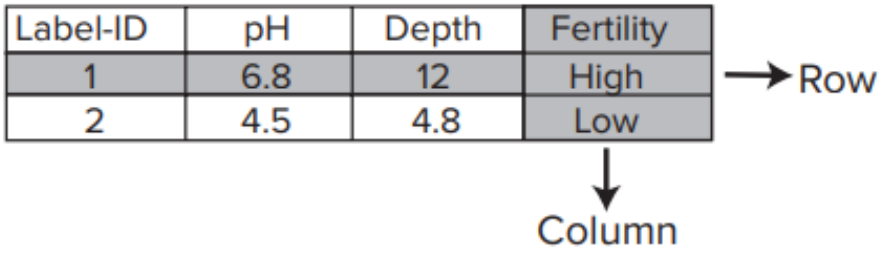
https://gisoutlook.com/2020/04/what-is-vector-data-model-of-gis.html

(pic nº 15): Real-world feature representation in vector dt format

4.3.1.2. The Attribute Data Model

The attribute data model represents the different entities of the information system and their relationships. The construction of such a model involves several stages depending on the level of abstraction: conceptual model or schema, logical model, physical model. The attribute model thus developed offers a solid structure that enables the optimization of data exchange between applications and the effective identification of real-world objects. (BoUAZiZ. S. & ReBAi.N, 2012)

Attribute data encompasses the numerical and descriptive information that further defines each resource. Geographic information is distinguished by a combination of attribute and behavioral values that specify spatial, graphical, textual, and quantitative characteristics. Examples include the identifiers, names, and physical properties of elements within a water resources system, such as dams, reservoirs, pipelines, drainage basins, pumps, and turbines. Additionally, time-series data, such as river flow rates, reservoir discharges, and pumping activity, are stored and managed within the attribute database.



From: (Chang, 2019)

(pic n°16): A feature attribute table

4.4. The human factor or liveware

A GIS is limited without the people who manage, design, develop, and update the data and information. These people can range from technical specialists to personnel who ensure the quality of the data and the

integrity of the final product. A GIS project usually involves professionals from various disciplines, such as geography, mathematics, computer science, statistics, biology, geology, sociology, economics, agronomy, geodesy, oceanography, among others, and the user staff. (Araque Rojas, 2014)

4.5. methods or procedures.

These are the specific methods, modes, and rules that describe how the technology is used. That is: specifications, standards, references, and methods for performing geographic information analysis.

5. Geographic information:

In the late 1960s, geomatics introduced a new form of expression for geographic information: digital form. This innovation allowed for a better understanding and more efficient use of spatial data. (Li. D.Shen. X.& Wang. L., 2018).

Almost everything that happens, happens somewhere. Over the years, we humans have carried out our activities on or near the surface of the globe: we build tunnels; we dig trenches to bury the various networks of pipes and cables such as water, gas and electricity; we build mines to exploit minerals; and we drill underground to access oil and gas wells. All these activities are of great importance, just as knowing where they are happening is.

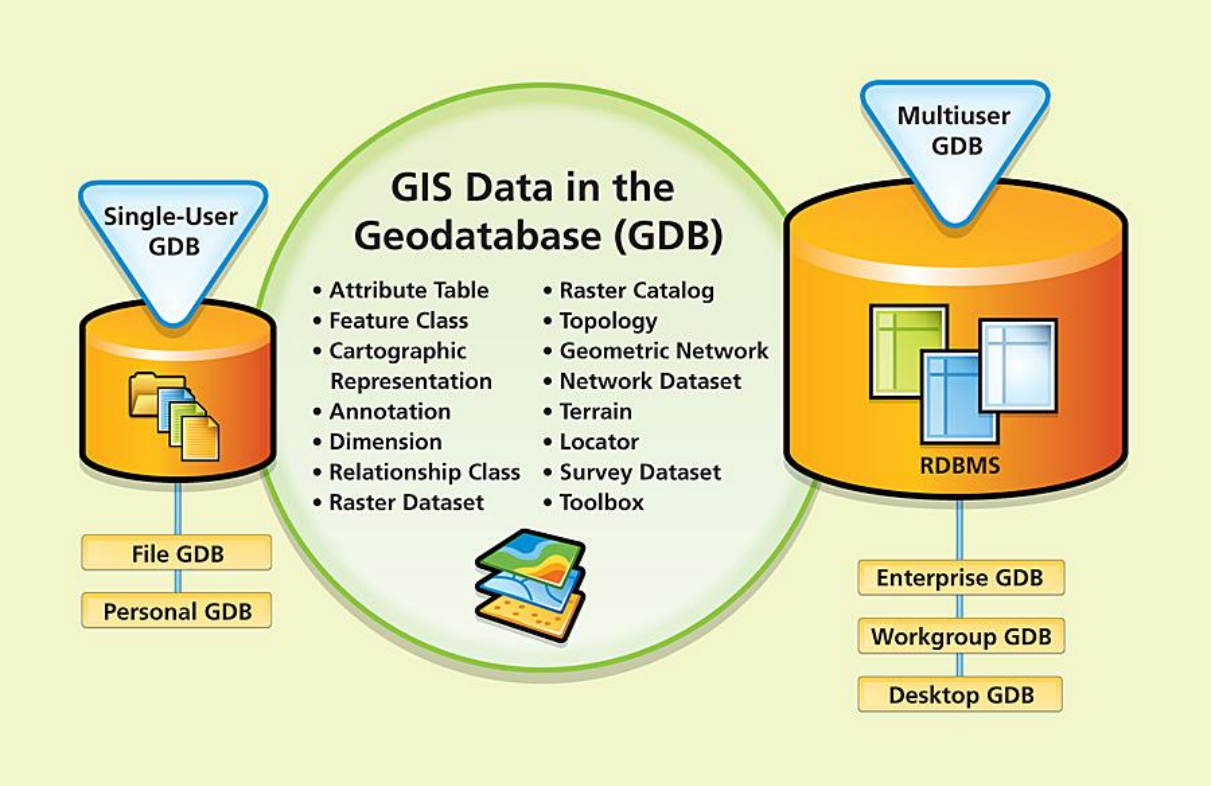
Knowing where something is happening is of vital importance if we want to go there or if we want to send someone there, and even if we want to find out some other information about that place or simply, for example, if we want to inform the people who live around it. Therefore, we can state that many (or perhaps all) political, strategic, and action-planning decisions about the territory have geographical consequences. (Lloret, 2009)

6. ELEMENTS OF GIS :

6.1. Geodatabase:

Data collection costs surpass those of software and hardware combined, accounting for approximately 70% of the total expenses required to produce the final output. Therefore, every data file incorporated into a GIS must include

metadata detailing the data's origin, reliability, accuracy, completeness, consistency, and timeliness. When handling large volumes of data, regularly updating information is also essential. To ensure data accessibility and usefulness for the widest range of users, the data must adhere to predefined standards or data transfer protocols (Gomarasca, 2009).



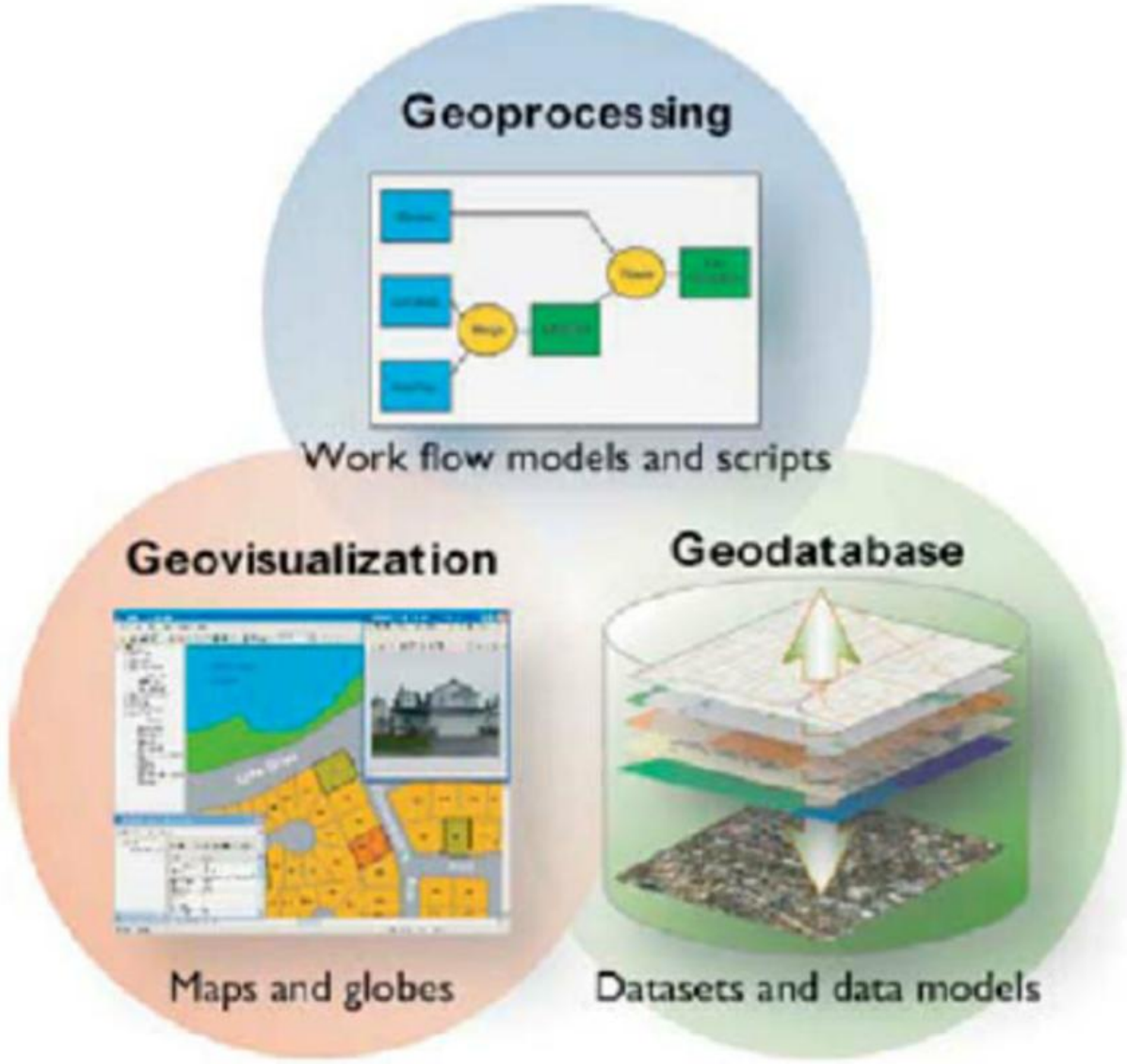
From: https://www.esri.com/news/arcnews/winter0809articles/the-geodatabase.html

(pic nº 17): the geodatabase

6.2. The geovisualisation element (ESRI, 2024)

A GIS is a set of intelligent maps and views that show entities and their relationships on the Earth's surface. It is possible to create different cartographic views of the underlying geographic information, which can be used as 'windows on the geographic database' to carry out queries and analyses, and to modify the geographic information.

Each GIS integrates several two-dimensional (2D) and three-dimensional (3D) cartographic applications offering a full range of tools for processing geographic information using these components.



From: https://www.researchgate.net/figure/Schema-extracted-from-ArcGIS-Reference-manual-showing-the-three-views-of-GIS_fig3_221908819

(pic n°18): the elements of a GIS

6.3. **The geoprocessing component** (ESRI, 2024)

A GIS includes information transformation tools that produce information from existing datasets. Geoprocessing functions take the information contained in

existing datasets, apply analytical functions, and write the results into new datasets.

Geoprocessing lets you schedule your work and automate workflows by creating an ordered sequence of operations.

7. GIS applications :

All human activities are related to geographic space; therefore, the range of applications for Geographic Information Systems is very wide. Among the most common applications are

7.1. Research:

- Environmental and spatial sciences.
- Development of models.
- Cartographic modeling.
- Dynamic models.

7.2. Corporate

- Marketing.
- Distribution strategies.
- Transport planning.
- Optimal location.

7.3. Management

- Cadastre.
- Territorial planning and planning of the territory.
- Inventory of resources.

8. Advantages of using GIS.

Chapter III. Remote sensing:

1. Earth observation

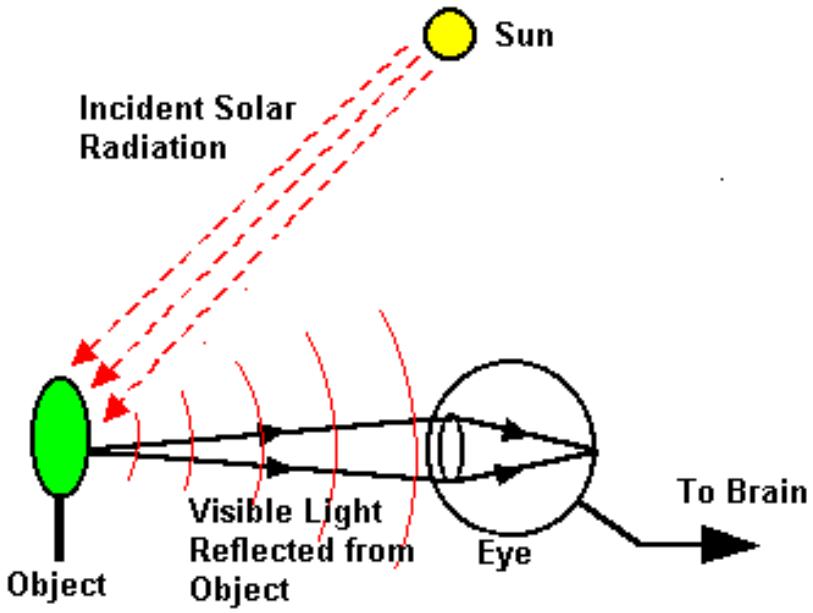
The history of Earth observation undoubtedly begins with the perspectives of early mountain climbers and the imaginative visions of expansive views enjoyed by soaring birds, such as hawks, eagles, and vultures. It was not until the 18th century, with the invention of hot-air balloons, that humans could ascend to significant heights and conduct scientific measurements from aloft. Prior to this, kites had famously been used by Benjamin Franklin to carry scientific instruments into the air. One of Franklin's experiments demonstrated that lightning is a form of electricity.

John Jeffries, a Bostonian physician who undertook two balloon flights with the French aeronaut Jean Pierre Blanchard—including the first perilous balloon crossing of the English Channel in January 1785—is recognized as the first person to conduct meteorological measurements from a balloon.

In the nineteenth century, the combination of photography and ballooning technology enabled the creation of the first aerial photographs. Among these were the images captured by Nadar (Gaspar Felix Tournachon) from his balloon, Le Géant, in 1858. Nadar's pioneering work inspired the character Michel Ardan in Jules Verne's 1865 novel From the Earth to the Moon, which tells the story of three adventurers launched into space by a giant cannon. (Eyres, 2017)

2. What is remote sensing?

Remote sensing refers to techniques used to obtain information about an object on the surface without direct contact, using sensors mounted on aerial or satellite platforms. A daily example of obtaining information without direct contact with the object is the human eye or a photographic camera when observing an object. (Araque Rojas, 2014)



From: https://crisp.nus.edu.sg/~research/tutorial/eye.htm

(pic nº 19): The Visual System

Definition of remote sensing:

Remote sensing, or spatial remote sensing, is a series of processes for obtaining information about the physical properties of objects, geological phenomena, natural resources, and anthropogenic activities based on measurements and observations made from a distance, i.e., without direct contact. (Soria. M. V. & Matar. M, 2016).

``Remote sensing is the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface``. (Campbell J. B., 2023)

3. **Milestones in the history of remote sensing**

(Campbell J. B., 2023)



From:https://gsp.humboldt.edu/olm/Courses/GSP_216/online/lesson1/history.html

Early beginnings (19th century):

Balloons carrying cameras were used to take the first aerial photographs, primarily for military and exploratory purposes.

Early 20th century:

- The invention of the airplane improved the possibilities of aerial photography. During the First World War, aircraft were used to gather photographic data in support of military operations.

Between the two world wars:

- The use of aerial photography developed for civilian purposes, such as mapping and forestry management.

World War II:

Sensor technologies took a quantum leap forward, with multispectral imaging and image analysis being used to identify military targets.

Post-1945:

- New concepts such as spectral sensing and atmospheric radiometers emerged. Pioneers such as Robert Colwell and Evelyn Pruitt played a pivotal role in establishing the foundations of modern, systematic sensing.

The Space Age (1972 onwards):

- The launch of the first Earth observation satellite, Landsat 1, was a defining moment.

- Satellites transformed remote sensing into a key tool for studying resources, the environment, and natural hazards.

The last few decades:

Technologies such as SAR, LiDAR, and thermal imaging have evolved. The openness of databases such as Landsat, along with improved image resolution, has helped to expand civilian and scientific uses. (Campbell J. B., 2023)

4. Physical basis of Remote Sensing

The physical basis of Remote sensing is based on the existence of energy flows whose variations can be detected and measured in their elementary parameters, of which the 'spectral' one is of particular interest to us in this topic (Soria. M. V. & Matar. M, 2016)

4.1. Electromagnetic energy

Does any natural or manufactured object generate radiant energy (wavelengths) at a temperature above O° Kelvin (K), energy that can be located in some region of the electromagnetic spectrum? Electromagnetic energy propagates at the speed of light. It has two characteristics: frequency (the number of waves passing through a point in a given time) and wavelength (the distance between peaks). (Araque Rojas, 2014).

4.2. The medium through which the EEM propagates, such as the atmosphere. This medium allows different processes of absorption and reflection of energy.

4.3. The different surface coverages that are necessary to recognize in order to know their behavior, since each type of object and coverage on the Earth's surface interacts differently with the EEM.

4.4. **The system or instrument** (sensor system) for detecting and measuring the variations caused by the presence of each object in the presence of the EEM.

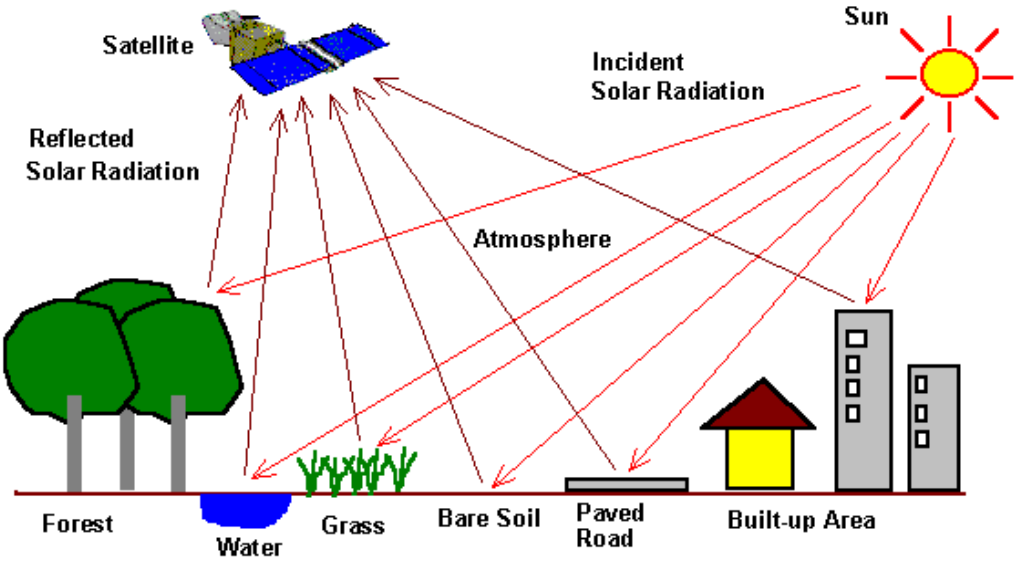
The sensor's technical characteristics influence data quality and the ability to receive information at different wavelengths. To recognize the function of each

of these elements in the remote sensing process, a brief overview of their roles and importance will be provided. (Soria. M. V. & Matar. M, 2016).

Sensors

A very common classification of remote sensing systems is based on how they operate in the field of EEM: passive sensors measure variations in energy from objects without intervening in the natural field; active sensors generate an artificial energy field and record and measure the effect of objects on it.

Passive sensors: These sensors require an external energy source, so they rely on sunlight to operate. This does not allow them to work at night; on the contrary, the preferred time to capture the information is at noon (12 hs), thus avoiding shadows. As its energy frequency corresponds to the visible and infrared (short wavelength), the presence of clouds interferes with the reception of the information. This type of sensor is widely used in the evaluation and inventory of natural resources and in urban planning in general. (Soria. M. V. & Matar. M, 2016)

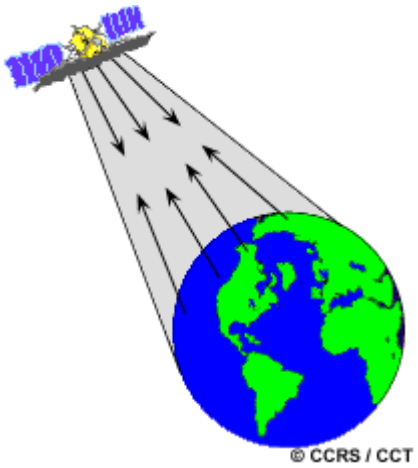


(pic nº 20): Passive sensors:

From: https://prvnkinetiks.blogspot.com/2014/07/remote-sensing-and-gis.html

Active sensors: These sensors can emit and detect their own energy, so they do not require an external energy source to operate. This allows them to emit and receive information at night, i.e., in the absence of sunlight.

As their energy frequency corresponds to radar waves (long wavelength), they can work in the presence of clouds, which do not present interference. These characteristics make it a widely used sensor in strategic activities, reconnaissance flights, and war planning. (Soria. M. V. & Matar. M, 2016)



(pic nº 21): Active sensors

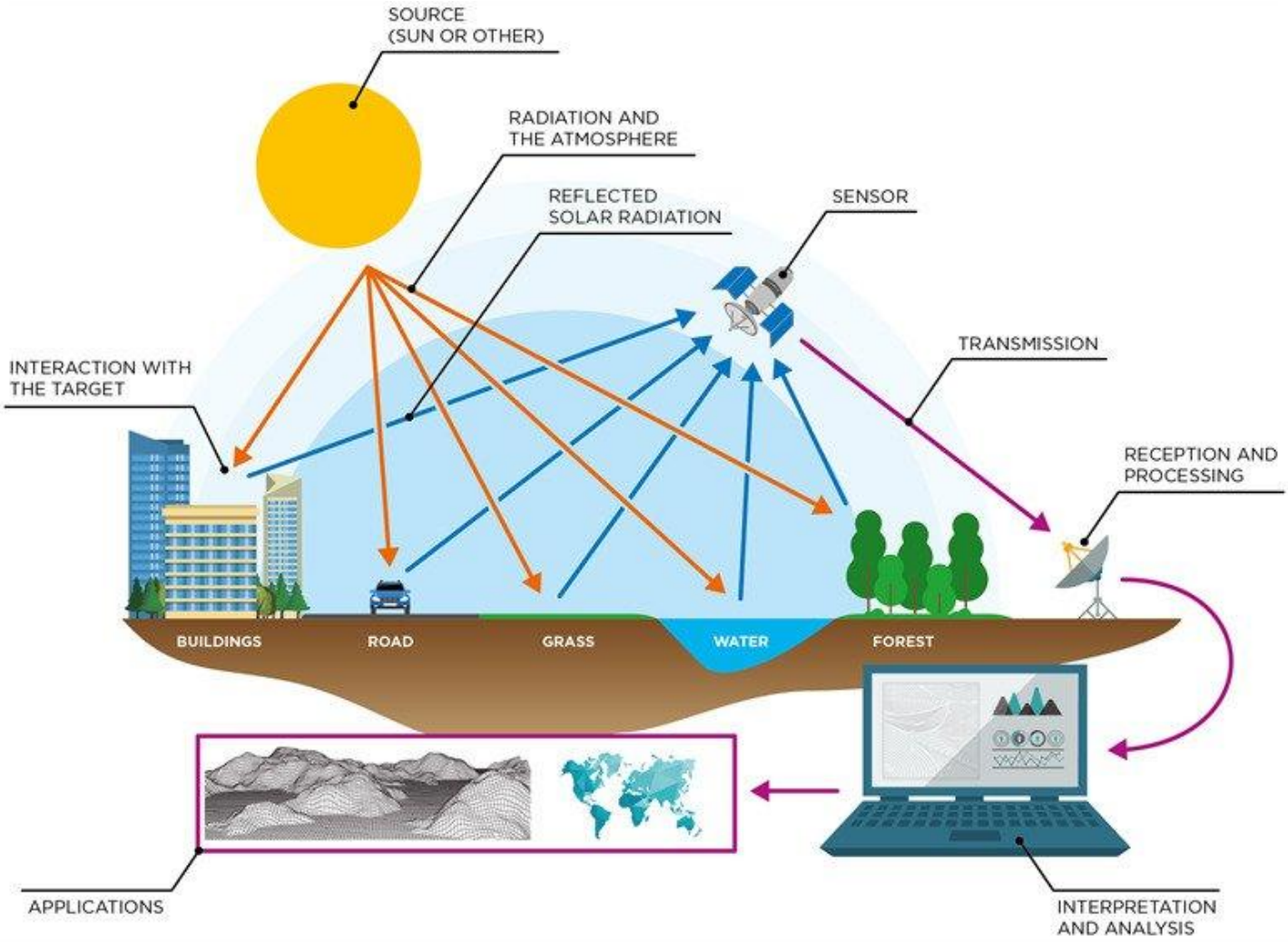
From: https://natural-resources.canada.ca/maps-tools-publications/satellite-elevation-air-photos/passive-vs-active-sensing

4.5. Properties of matter: reflection, absorption, transmission. Radiation reaching the Earth's surface

takes different directions (some is scattered in the atmosphere, some is absorbed, some is transmitted, and objects reflect some on the surface)

In remote sensing, the energy of interest for analyzing objects on Earth's surface is the energy reflected and emitted by the objects (including temperature measurements). (Araque Rojas, 2014).

5. Operating principles

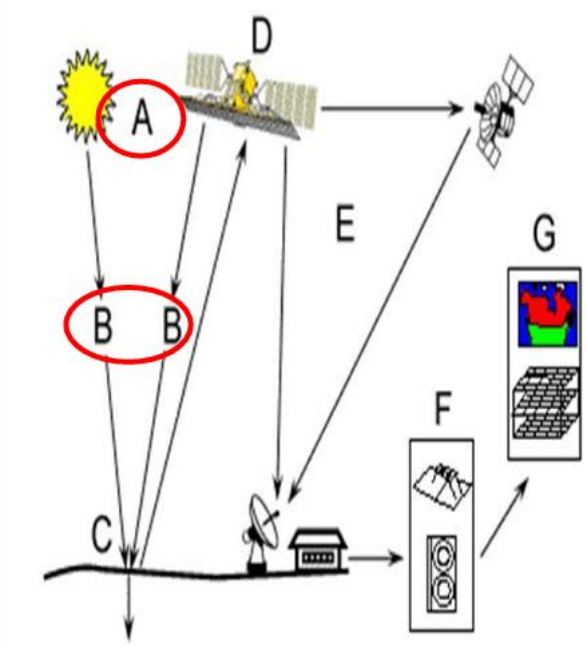


(pic n°22): Remote Sensing Process, EMR

From: https://geolearn.in/the-basic-concept-of-remote-sensing/

(A) Energy source or illumination – the first requirement for remote sensing is an energy source.

source to illuminate or provide electromagnetic energy to the target of interest.



(B) Radiation and the atmosphere: As a gaseous medium of EEM transmission, the atmosphere plays an important role in remote sensing processes. As the energy travels from its source to the target, it will interact with the atmosphere through which it passes. This interaction may take place a second time as the energy travels from the target to the sensor. The atmosphere does not behave as a transparent body, but directly influences the quantity and intensity, frequency, and distribution of the spectral energy directly received by the sensor.

Among the modifications that electromagnetic energy undergoes, Chuvieco (2002) highlights the following:

The phenomenon of atmospheric dispersion ("scattering") appears due to the diffusion in one or more directions of the energy due to the particles in suspension and the molecules of the components of the atmosphere. In general, this scattering effect decreases with increasing wavelength.

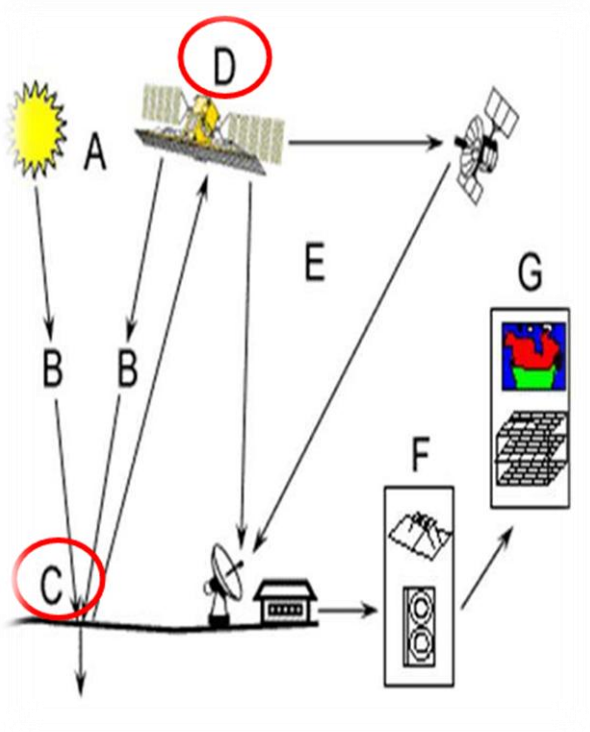
Atmospheric absorption is related to the retention of energy by the different components of the atmosphere, especially water vapour (H2O), carbon dioxide (CO2), oxygen (O2) and ozone (O3). This effect is very selective, being limited to certain wavelengths within the electromagnetic spectrum (those below 0.3 ìm for ozone, for example). from the target to the sensor.

Those regions where these processes are weak and therefore there is good energy transmission, making it easier for the energy to be received by the sensor, are called ‘atmospheric windows’.

These areas of the atmosphere focus especially on the ultraviolet, visible, reflected and thermal infrared, in addition to wavelengths longer than 1 mm, where atmospheric transmission is total, which is one of the main reasons for its frequent use in radar remote sensing. (Soria. M. V. & Matar. M, 2016).

(C) **The behavior of land cover (target)**

Once the energy has made its way to the target through the atmosphere and interacts with the target (G Inst. Biruk, 2020), it is possible to record three types of variations in objects using a remote sensing system: spectral, spatial, and temporal.



Every object on the Earth's surface reflects or emits EEM according to a function that depends on its wavelength; thus, each material or object has a characteristic spectral behavior, called spectral signature.

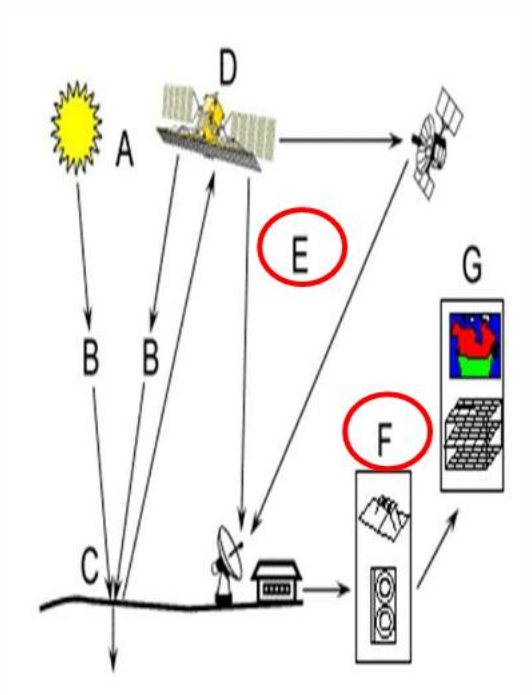
(D) **Recording of energy by the sensor:** After the energy has been scattered by or emitted from the target, a sensor is required (G Inst. Biruk, 2020) capable of capturing and measuring the energy coming from the objects. Electromagnetic radiation. (remote, not in contact with the target) to collect and record it, each object will appear on the screen or image with its specific signature, a value Xi

unique to it, for each wavelength recorded by the sensor. In this way, it is possible to have numerical spectral data that will trace a curve according to the

wavelength, which will be particular to each material on the surface. (Soria. M. V. & Matar. M, 2016).

Reception and processing (E):

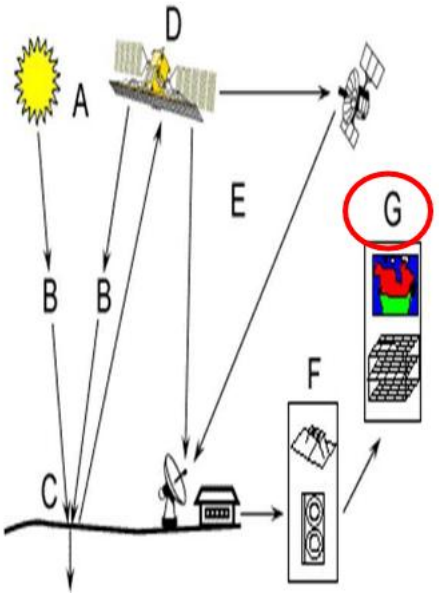
Energy recorded by the sensor must be transmitted electronically. to a receiving and processing station, where the data are processed into an image (hard copy and/or digital form.



Interpretation and analysis (F):

The processed image is visually and/or digitally or electronically interpreted to extract information about the illuminated target. (G Inst. Biruk, 2020).

Application (G): The final stage of the remote sensing process involves using the information derived from the imagery to gain a deeper understanding of the target, uncover new insights, or solve a specific problem. (G Inst. Biruk, 2020)



6. Electromagnetic radiation

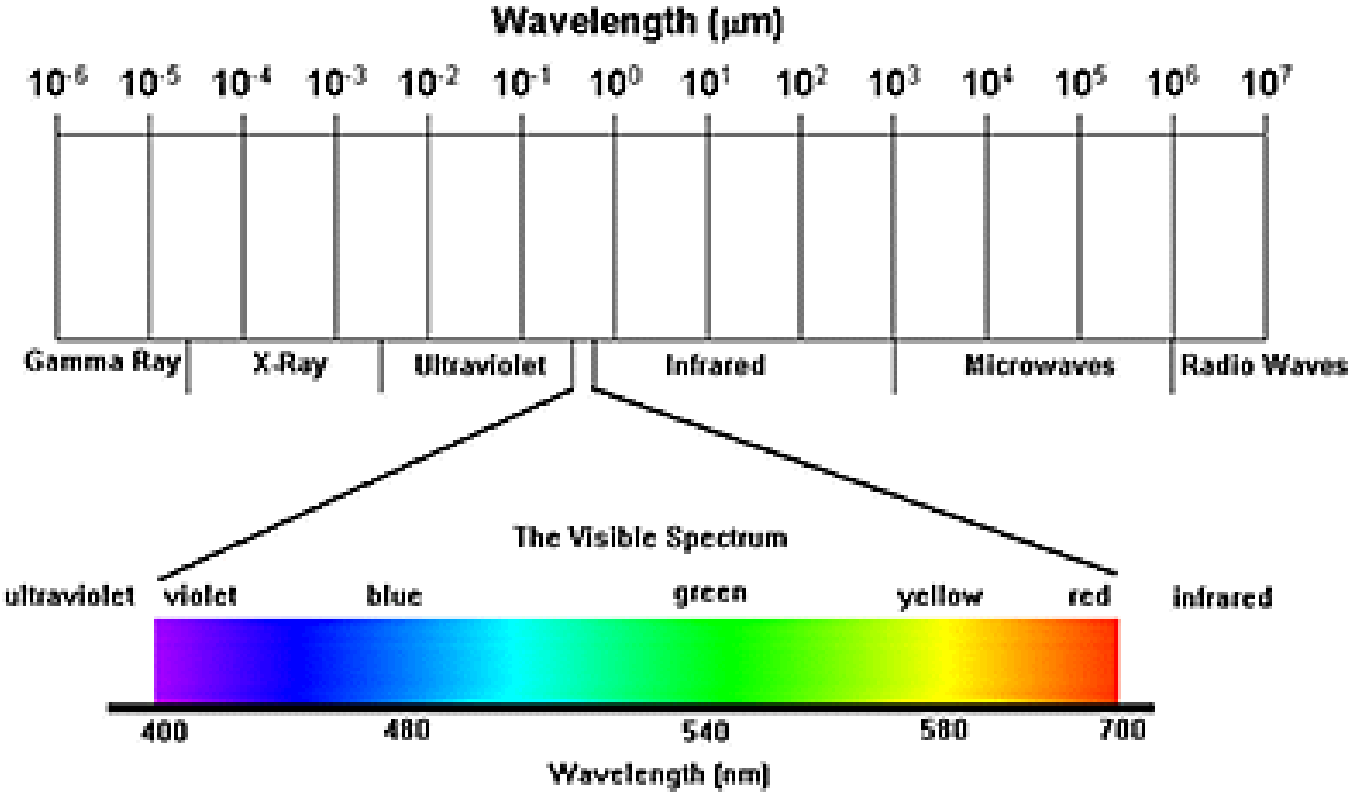
The energy originating from a source of electromagnetic radiation is characterized by vibration and transmission in the form of waves whose different wavelengths (or frequencies) define the electromagnetic spectrum. The wavelength is usually identified by the Greek letter lambda (ƛ) and can be measured in angström (Ä), in microns (µ), in nanometers (nm), in centimeters

(cm), in metres (m) or in kilometres (km) according to the following equivalence: (Soria. M. V. & Matar. M, 2016)

1 Ä = 10-10 m = 10-7 mm = 10-4 µ

1 nm = 10 Ä = 10-6 mm = 10-3. µ

Wavelength is the inverse of frequency measured in cycles per second (cps), but in remote sensing and remote sensing it is customary to always speak of wavelengths. Figure 4 shows a diagram of the EM spectrum detailing the behaviour of waves from a few hundredths of angström (gamma ray sector) to several kilometres (current electrical energy), the latter being equivalent to 1cps. (Soria. M. V. & Matar. M, 2016)



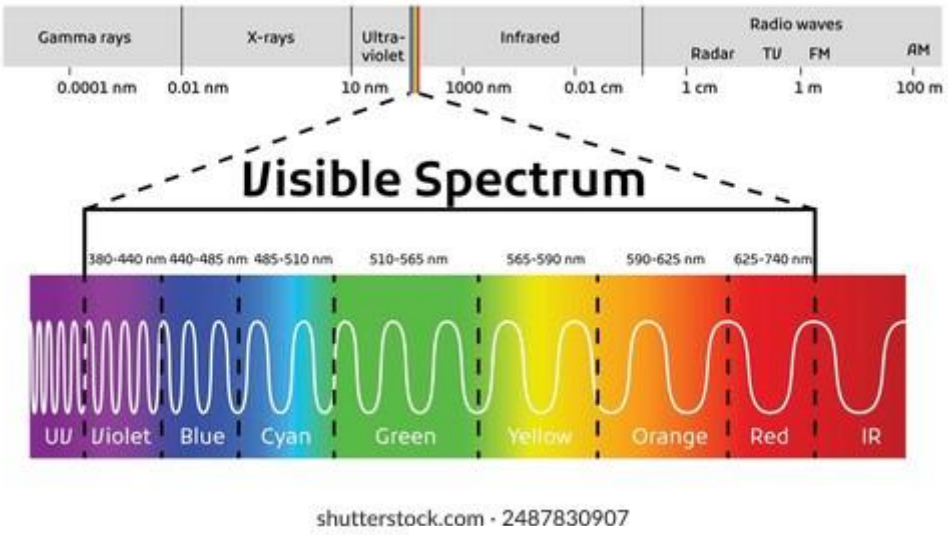
(pic nº 23): The electromagnetic spectrum and its wavelengths.

From: https://crisp.nus.edu.sg/~research/tutorial/em.htm

Major divisions of the electromagnetic spectrum

- **The visible spectrum.**

There is a band of the EM spectrum that is of particular interest, called the "visible spectrum, where the waves naturally detected by the human eye are located. Thus, the diagram can be subdivided into three sectors (Soria. M. V. & Matar. M, 2016).



From: https://www.shutterstock.com/search/visible spectrum?dd_referrer=https%3A%2F%2Fwww.google.com%2

(pic nº24): The visible spectrum.

The ultraviolet: To the left of the 'visible' band (shorter waves) is the ultraviolet (UV), X-rays, alpha rays, and at the extreme end gamma and cosmic rays;

In the center is the visible spectrum, which varies from violet (or indigo blue) at its shortest length to red at its longest;

NIR (near-infrared region): The NIR spectrum (about 0.7 µm–1.4 µm) lies outside the visible spectrum, is valuable mainly because it is not subject to atmospheric scattering. It is also effective in detecting and monitoring living vegetation.

VNIR (visible and near-infrared region): The VNIR (0.4–1.4 μm) is defined as the full visible spectrum, extended to include the adjacent region of the infrared spectrum.

• **SWIR (shortwave infrared region):** The SWIR (sometimes defined as 0.9–1.7 μm

or 0.7–2.5 μm) is effective because it is not subject to atmospheric scattering. Yet it is still effective for mapping minerals, fires, crop health, and surface moisture.

• **Thermal: Thermal radiation,** designated here by its broad range

of wavelengths within the 8–14 μm atmospheric window, conveys temperature information. (Campbell J. B., 2023)

The infrared (IR) bands, radar, TV and radiometers**.** IR is usually differentiated into near (0.7 to 1.2 μ), medium (1.25 to 3.00 μ), and far (3.0 to 15 μ). Another very common classification separates the IR into reflective (0.7 to 3.0 μ) and emissive or thermal (3.0 to 15.0 μ). (Soria. M. V. & Matar. M, 2016)**.**

Division	limits
Gamma rays	< 0.03 nm
X-rays	0.03–300 nm
Ultraviolet radiation	0.30–0.38
Visible light	0.38–0.72 μm
Infrared radiation **Near infrared** **Mid infrared** **Far infrared**	 0.72–1.30 μm 1.30–3.00 μm 7.0–1,000 μm (1 mm)
Microwave radiation	1 mm–30 cm
Radio	≥ 30 cm

(Campbell J. B., 2023)

7. Satellites

Definition:

Satellites are platforms that orbit around the Earth, where the Sensors, which are the devices installed to capture, store, and transmit images known as satellite images useful for Earth observation, are located. (Araque Rojas, 2014)

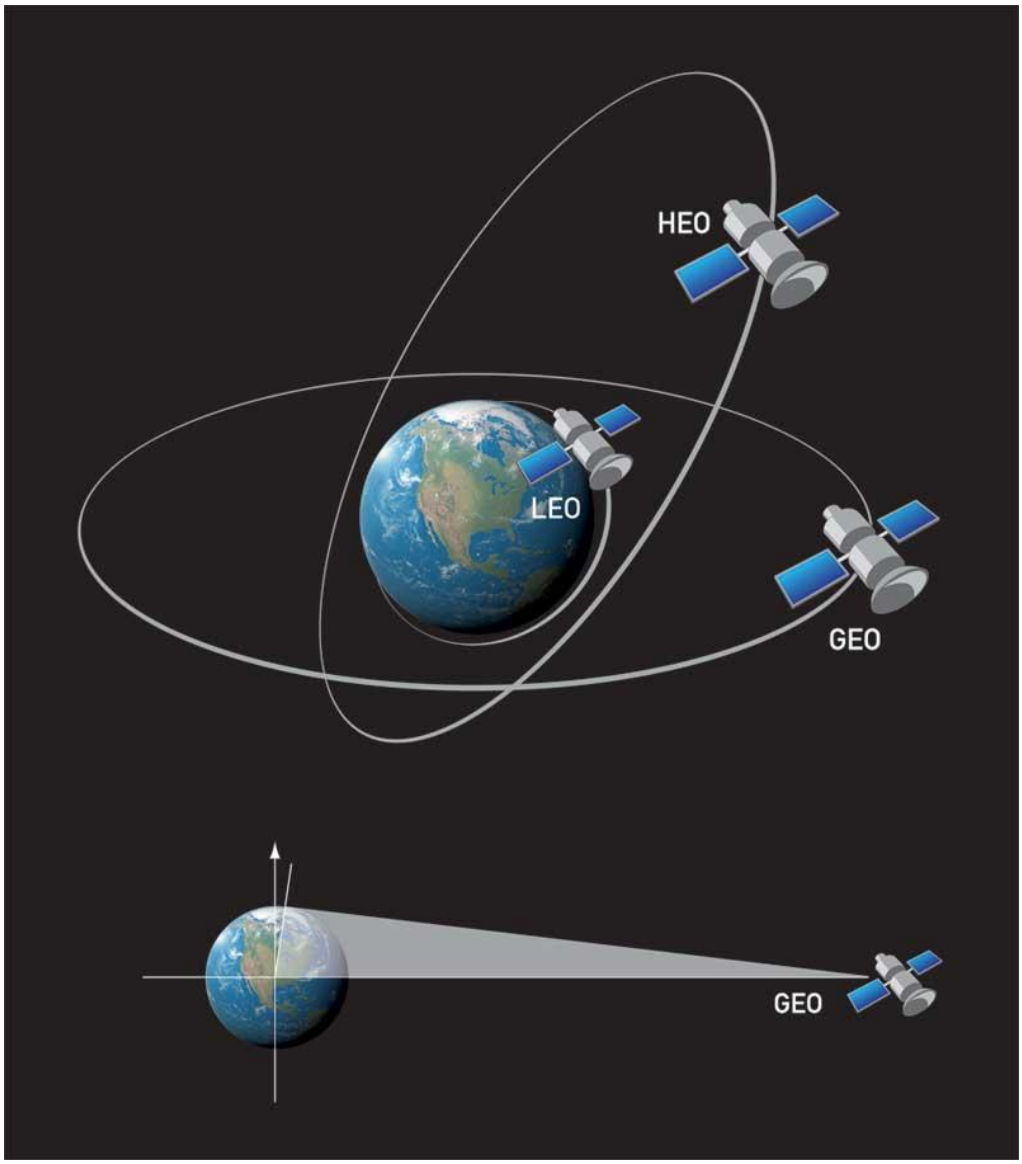


From: https://parlonssciences.ca/ressources-pedagogiques/documents-dinformation/introduction-aux-...

(pic n°25): satellites.

Types of satellites according to their orbit and coverage

Geostationary orbit satellites: are satellites located in an orbit in which they follow the rotational motion of the Earth, i.e., they have an orbital rotation period equal to that of the Earth. In general, these satellites record climatic information, which allows them to recognize the directional sequence of a hurricane, the movement of air masses, among other things. (Soria. M. V. & Matar. M, 2016).



(pic nº 26): Communication satellites orbiting the Earth in geostationary orbits (GEO), Low Earth Orbits (LEO), and High Elliptical Orbits (HEO).

From: https://www.researchgate.net/figure/Communication-satellites-orbiting-the-Earth-in-geostationary-orbits-GEO-Low-Earth_fig3_266670547

Polar-orbiting satellites: All civil remote-sensing satellites circle the globe in near-polar orbits, moving in a slightly northeast-southwest direction in descending orbits that take them directly over the poles on each orbit. The passes over each point on the Earth's surface are made at constant speeds and altitudes, with a periodicity that ensures systematic data collection. (Soria. M. V. & Matar. M, 2016).

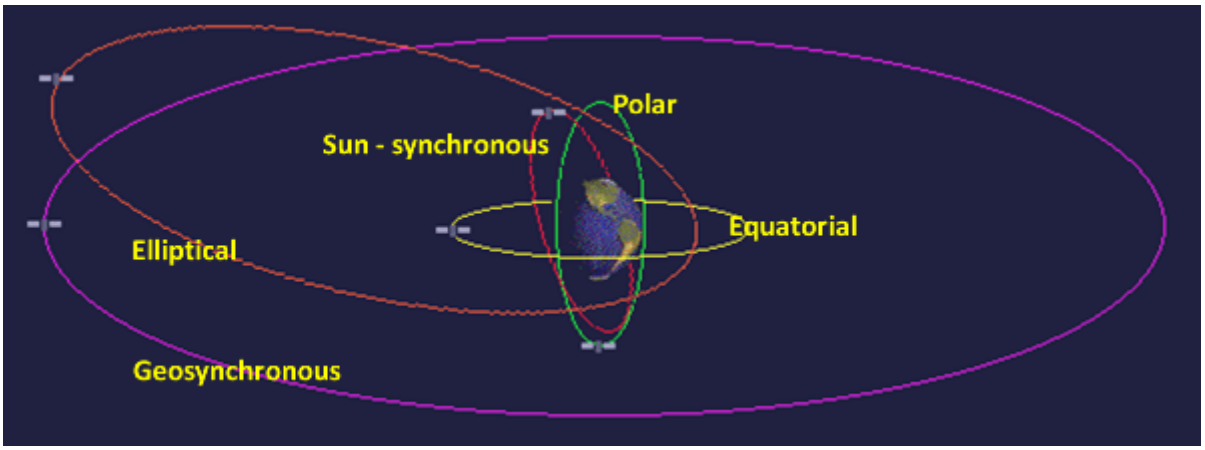


From:https://img.brainkart.com/imagebk37/ggbdUbW.jpg

(pic nº 27): Polar orbit and geostationary satellites.

Sun-synchronous orbit satellites :

Sun-synchronous orbit satellites acquire images during solar illumination. They are located at altitudes between 600 and 900 km. Their orbit is almost polar, so it is possible to observe different areas of the planet on each pass (Araque Rojas, 2014).



(Pic nº 28) : Sun-synchronous orbit satellites

From: https://iasmania.com/types-of-satellite-orbits/#google_vignette

5. Multispectral signatures

The electromagnetic spectrum

These are the different regions where all the wavelengths of existing electromagnetic radiation are grouped together. Starting from short wavelengths, a few µm (micrometres), up to high long wavelengths (km). Figure 2.5 shows the regions of the electromagnetic spectrum in terms of wavelengths. visible light is the range of wavelengths to which the human eye is sensitive. The ranges that are in the visible correspond to the colours: violet and blue are the lowest, the highest are seen as red, and the intermediate ones are perceived as green and yellow, etc. (Araque Rojas, 2014)

6. Resolution

Every sensor has a capacity to distinguish elements, which some authors call 'limitations' to obtain information. Capacity, known as 'resolution', of which there are several types:

- Spectral Resolution.
- Radiometric resolution.
- Angular resolution. (Araque Rojas, 2014)

- Spatial Resolution.
- Temporal Resolution.

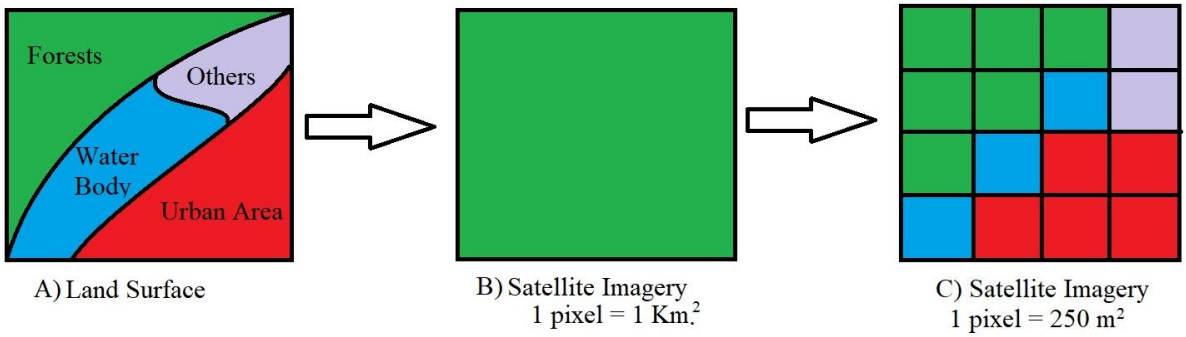
For this lecture, only spectral, spatial, and temporal resolution will be explained.

Spectral Resolution

Refers to the number and width of spectral bands that the sensor can capture. For example, which bands of the visible and infrared IR) spectrum

Spatial Resolution

Refers to the smallest object that can be identified in an image, i.e., the smallest identifiable unit called a pixel (Picture element), and each image from a sensor has a defined pixel size. (Araque Rojas, 2014)



(Pic nº 29): Spatial Resolution

From: https://pangeography.com/types-of-resolution-in-remote-sensing/

Temporal Resolution

Refers to the time between shots, i.e., how often the sensor picks up a new image of a particular area. Examples of this are presented in the image sequence for the Valencia lake basin, Aragua-Carabobo states, and Lemna monitoring in Maracaibo Lake, Zulia state (Araque Rojas, 2014)

Fields of application of remote sensing

The primary objective of remote sensing (RS) is to produce maps, primarily thematic but also topographic. Its fundamental characteristics as a source of georeferenced information are:

• A synoptic view of the ground surface that is otherwise unobtainable with traditional techniques.

• A repeating cycle of periodic observations that enable temporal comparisons and updating of the collected data.

Multispectral acquisitions are also a fundamental characteristic of RS.

• The acquisition of information with remote sensing techniques is developed in three phases:

- Collection of data from ground, aerial, and/or satellite acquisition stations.

- Processing of the collected data;

- Data interpretation is followed by the restitution of thematic cartography, either in hardcopy or digital form. (Gomarasca, 2009).

• Natural resources management.

• Urban control and management.

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