PHYSICAL OCEANOGRAPHY AND BIOGEOCHEMISTRY
OPCB 201 – MEASUREMENTS AT SEA

1) A brief history
2) Repository - mapping
- map projections
- Mercator, Gall-Peters, Lambert, Goode, … projections

3) Position at sea
- dead reckoning
- navigation by stars
- distances (great circle – rhumb line)
- nautical charts
- GPS

Reminder: Sampling for the practicals (TDs)
4) Measuring T, conductivity, P, derived quantities (potential and conservative temperature, salinity, density, specific volume, specific volume anomaly, density, excess density, sigma, speed of sound), time
5) Oceanographic instruments
6) Measuring current velocity

Special COPERNICUS program

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Translation done by Oliver Ross, XpertScientific.

References (non exhaustive list)

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Pickard, G. L. and W. J. Emery (1990). Descriptive physical oceanography, Pergamon Press

Pollard, R. and J. Read (1989). "A method for calibrating Shipmounted Acoustic Doppler Profilers and the Limitations of Gyro Compasses." J. Atmos. Ocea. Techn. **6**: 859-865.

R.D.I. (1989). Acoustic Doppler Current profiler Principles of operation: A practical primer. Research Development Instrument**:** 41. (à prendre sur site web)

Web sites (non exhaustive list; others are cited along in the course)

http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html (Introduction to physical oceanography, by Rob Stewart, Univ. Texas A&M)
http://isitv.univ-tln.fr/~lecalve/oceano/plan.htm
http://www.univ-lemans.fr/~hainry/articles/loxonavi.html
http://www.wetlabs.com
http://www.ifremer.fr/dtmsi/produits/marvor/provor.htm
http://www.rdinstruments.com/rdi_library.html#primers
http://wikipedia.org
(+ additional web sites provided during the course)

CHAPTER 1 - A) A BRIEF HISTORY

Names with * are discussed below

	Who	Explored regions	Reasons	Knowledge
- 4000	Egyptians	Nile + Eastern Mediterranean		
-4000	Polynesians	Pacific Ocean	Eastward migration	Stars, currants, animal migrations
-2000 -1400	India			Description of tides (link with sun and moon)
- 1000 - 600	Phoenicians	Mediterranean	Small size of their territory (~ Lebanon)	Excellent navigators; navigation at night using the Little Dipper which the Greeks called "the Phoenician"
- 330	Pytheas	Eastern Med., GB, Norway, Iceland		Latitude (angle between north star and horizon)
-284	Eratosthenes*			Earth's circumference of 40,000 km (inclination of the sun + distance Alex. – Aswan)
127 151	Ptolemy*			World "Atlas" (without Americas); with a circumference of 29,000 km
700- 1000	Vikings	Iceland, Greenland, Newfoundland	Colonisation	
900 + Middle Ages	Arabs	Africa (East) Zanzibar China	Trade	Wind reversal, Indian Ocean currents
1405-1433	Cheng Ho/Zhen He (Chinese admiral)	Indian Ocean	Control the empire of his emperor	1st map that included America?
1487-88 1492-94 1497-99	Bartolomeu Dias Christ. Columbus Vasco da Gama	Africa (South) America Africa (South)	Interruption of the trade routes to India (taking of Constantinople by Sultan	Rediscovery of the Ptolemy's geometrical map Arrival of the compass* (replacing the wind rose) Knowledge of trade winds, coastal currents

1519-1522 1577-80	Magellan Drake	World tour World tour	Mohammed II in1453)	1507 * Waldseemüller map including America
		BEGINNING OF SCIENTIFIC EXPEDITIONS		
1768-1779	James Cook	World tour and Pacific Ocean; New Zealand (Endeavour, Resolution, Adventure)		
1809-1882	Charles Darwin	World tour (Beagle)		
1818-1851	Sir James C. Ross + Sir John Ross	Arctic and Antarctic		
1820	Baltic Baron Fabian von Bellingshausen	Circumnavigation of Antarctica		
1815-1854	Edward Forbes	Vertical distribution of life in the ocean		
1893-1896	Norwegian Fridtjof Nansen	Expedition to the North Pole (Fram) Verified the existence of an Arctic Ocean; proof that ice at sea was indeed sea ice and not from a glacier		
1945		Knowledge of nearly all coasts (except some in the Arctic and Antarctic)		
20th century	SATELLITES	Complete observation of the Earth's surface		

Herodotus ca. 450 BCE [https://en.wikipedia.org/wiki/Herodotus]

The only work that we know of Herodotus is called “The Histories”, from Greek Ἱστορίαι / *Historíai* — literally “research, explorations”, by ἵστωρ, “him who knows”. It is one of the longest works of Antiquity.

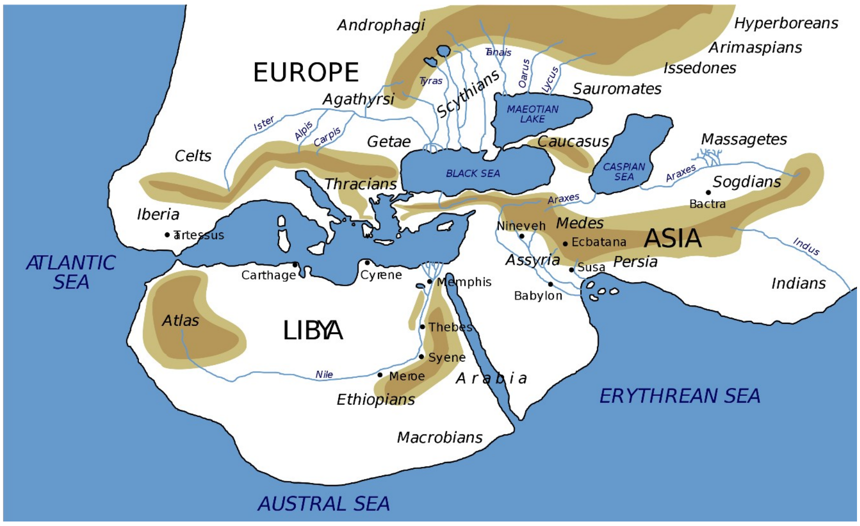

Figure 1: Map of the known World as described by Herodotus in his Histories

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Erathosthenes [https://en.wikipedia.org/wiki/Erathosthenes]

Eratosthenes (in old Greek Ἐρατοσθένης / Eratosthénês) was a Greek astronomer, geographer, philosopher, and mathematician (born 276 BCE in Cyrene - now Shahhat - in modern Libya, died 194 BCE in Alexandria, Egypt). He was a student of Aristo of Chios.

In 245 BCE, Eratosthenes was appointed Chief Librarian at the Library of Alexandria by Ptolemy III, then pharaoh of Egypt, and became to tutor to the pharaoh’s son. Having been a passionate astronomer all his life, legend has it that once he became blind he would let himself starve to death as he could not longer admire the stars.

Measuring the Earth’s circumference

Eratosthenes deduced the Earth’s circumference (or meridian) using a purely geometric approach.

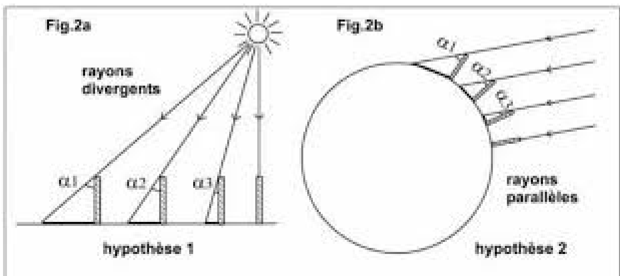
He observed the shadow of two objects located in two places, Syene (today Aswan) and Alexandria, on June 21 (summer solstice) at local solar noon. At this precise time of the year, the sun is at its highest position above the horizon in the northern hemisphere. Eratosthenes noticed that on that day there was no shadow in a well in Syene (which is roughly located on the Tropic of Cancer); thus, at this precise moment, the Sun was vertical and its light fully illuminated the bottom of the well. Eratosthenes also knew that on that same day at the same time, an obelisk located in Alexandria would cast a shadow, meaning that the Sun was not directly vertically above the obelisk which therefore had an off-centre shadow. Using trigonometric calculations, Eratosthenes deduced that the angle between the solar rays and the vertical was 7.2 degrees. Two hypotheses were then possible:

- The Earth is flat, but the Sun is sufficiently close so that ray divergence is significant, i.e., the solar rays reaching Earth are not parallel.

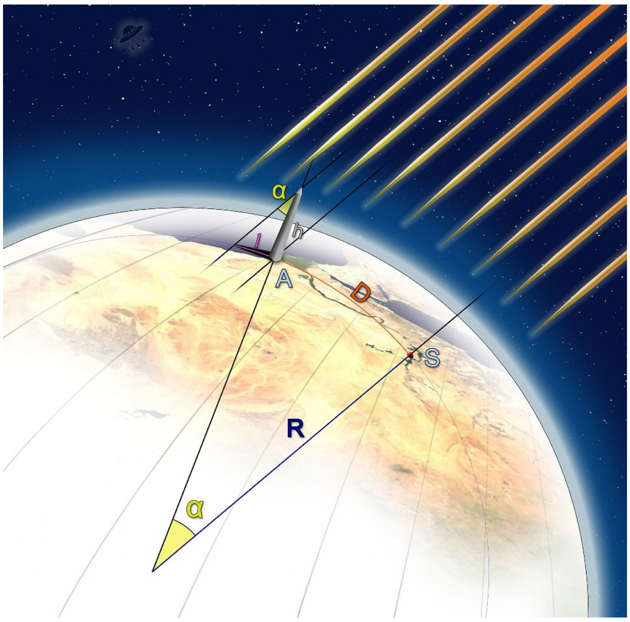
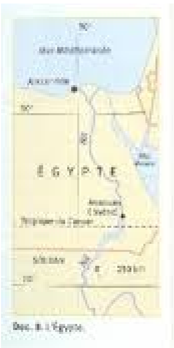
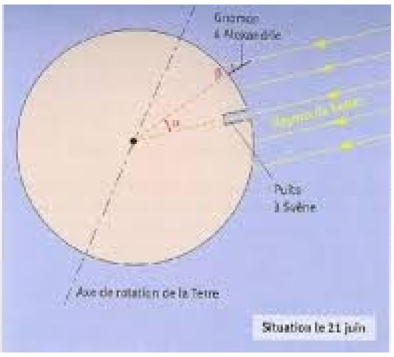
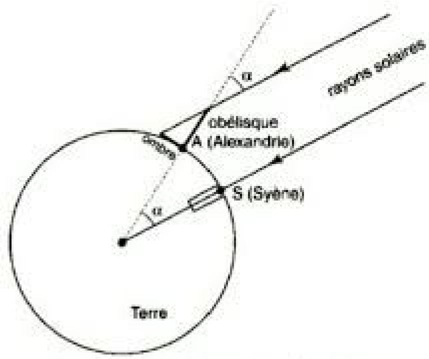
- The Earth is curved, perhaps spherical, and the sun is sufficiently distant that its rays reaching Earth are all parallel; in this case it is the Earth's curvature that creates the observed difference between Alexandria and Syene.

Sailors of all countries had always known about the curvature of the Earth (or at least the sea) as evidenced by the elevated positions of terrestrial lighthouses and crow's nests (lookout platforms in the upper part of a ship's main mast) of ships. Following Pythagoras (580-495 BCE) and Aristotle (384-322 BCE), Eratosthenes was also one of the first "scholars" to state the hypothesis of a spherical Earth.

Eratosthenes then approximated the distance between Syene and Alexandria by calling on a bematist (surveyor in ancient Egypt in charge of measuring distances by counting their number of "bêma" steps). The measured distance between the two cities was 5000 stadia or 787.5 km, which, if we assume that a stadium (length used in the stadiums of Olympia or Delphi) was about 157.5 m, is very close to the actual value.



La célèbre expérience d'Eratosthène donne lieu à la même observation sur un modèle de Terre plate avec un soleil proche (hypothèse 1) que sur une Terre globe avec un soleil très éloigné. (hypothèse 2)

	 https://en.wikipedia.org/wiki/Eratosthenes
  http://www.saga-geol.asso.fr/ Geologie_page_conf_forme_Terre.html	 Mesure du rayon de la Terre par Ératosthène. https://alzazou.wordpress.com/2018/07/28/la-terre-est-ronde-depuis-eratosthene/

Calculating the Earth's circumference

Using trigonometry, Eratosthenes proposed a figure of "*dazzling simplicity*": it consisted of a simple circle with a central angle of 7.2 degrees that intercepted an arc (linking Syene and Alexandria) of nearly 800 km:

- 5000 stadia at 157.5 m correspond to 787.5 km (and form an angle of 7.2°)
- A full circle of 360° contains 50 arcs of 7.2°

Using trigonometric ratios (already known at the time), he obtained the Earth's circumference as:

- 787.5 km × 50 = **39,375 km**, impressively precise for the time (current measurements give 40,075.02 km).

His idea of a spherical Earth only becane accepted again in the 13th century, when Thomas Aquinas aligned the positions of the Church with the views of Aristotle (prior to Eratosthenes) on scientific matters: Aristotle considered the Earth to be round and fixed at the centre of the universe.

Ptolemy ca. 150 CE [source: https://en.wikipedia.org/wiki/Ptolemy]

Claudius Ptolemy (in Greek: Κλαύδιος Πτολεμαῖος), commonly known as Ptolemy (Ptolemy ‘the Alexandrian’, born ca. 90 CE, died ca. 168 CE) was a Greek mathematician, astronomer, astrologer, geographer, and music theorist who lived in Alexandria (Egypt).

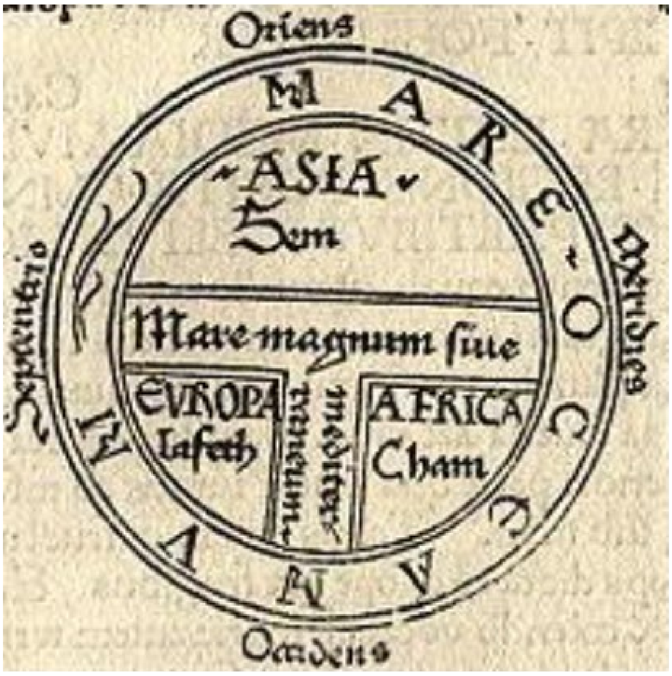
Ptolemy wrote about a dozen scientific treatises, the second of which was entitled Geography and consisted of a thorough discussion of maps and the geographic knowledge of the Greco-Roman world.

The world map according to Ptolemy, reconstructed based on his work Geography (ca. 150 CE), including the countries of Serica, Sinae (China) on the far right, beyond the island of Taprobane (Sri Lanka, too large) and Aurea Chersonesus (South-East Asia).

A printed map from the 15th century depicting Ptolemy's description of the Ecumene by Johannes Schnitzer (1482).

Medieval map

This T and O map, from the first printed version of Isidore's Etymologiae (7th century), identifies the three known continents as populated by descendants of Sem (Shem), Iafeth (Japheth) and Cham (Ham)
The book was written in 623 and first printed in 1472 at Augsburg by one Günther Zainer (Guntherus Ziner), Isidor's sketch thus becoming the oldest printed map of the Occident.



Waldseemüller map from 1507 containing a representation of the new continent + Pacific Ocean (depicted here 1 century before the first European would actually see it). This map was the first to include the Americas (unless the Chinese map by Zheng He from the beginning of the 15th century 1400-1430 should turn out to be authentic).

Chinese map including a representation of the new continent + Pacific Ocean
Map known as *Liu Gang*, presented par Gavin Menzies as a reproduction (done in 1763) of a map dating from 1421 and showing that Admiral Zhen He (also written as Chen Ho) circumnavigated

the world.

The map dates from 1763, although there is still an ongoing controversy about whether this may merely be a copy of a European map from the 17th century (see http://www.1421exposed.com/html/about.html for more details about the arguments of those opposing Menzies' theory) or a copy of an older Chinese map (from 1421).

(Source: https://en.wikipedia.org/wiki/Gavin_Menzies#1421:_The_Year_China_Discovered_the_World)

3D representation of the world

It is extremely rare, very expensive, and reserved for representatives of power.

To have a world map where 1 nautical mile would correspond to 1 mm, we would need a sphere with a radius of 3.40m. The following globes are examples (diameter almost 5m) but they were obviously not transportable on a ship of that time.

E.g., Coronelli's Globes
Cardinal d'Estrées, King Louis XIV's French ambassador to the Holy See, had the Italian cartographer Coronelli make two large globes for the king. Manufactured in Paris between 1681 and 1683 by Vincenzo Coronelli, "the greatest globe maker of all time" (Helen Wallis, " Biography of Coronelli", Amsterdam, 1969, p.18), these two spheres, one terrestrial and the other celestial, measure 387 cm in diameter and weigh about 2 tons each. The diameter reaches 487 cm if we include the meridians and the horizon circles (mobile) [on display at the National Library of France, Paris].


COMPASS [https://en.wikipedia.org/wiki/Compass]

A compass is a device that shows the cardinal directions used for navigation and geographic orientation. It commonly consists of a magnetized needle or other element, such as a compass card or compass rose, which can pivot to align itself with magnetic north, not to be confused with the geographic north. The difference between the two is called magnetic declination.

Compasses often show angles in degrees: north corresponds to 0°, and the angles increase clockwise, so east is 90°, south is 180°, and west is 270°. These numbers allow the compass to show azimuths or bearings which are commonly stated in degrees. A compass can be used in conjunction with a clock to be used for navigation.

History of the compass

There is some disagreement regarding the precise date on which the compass was invented. The oldest known compasses were used by the Chinese in the 2nd century, who typically used it for geomancy. Their compasses then looked like tablespoons. Oddly enough, it took some time for this phenomenon to be used by the Chinese for naval navigation, but by the 11th or 12th century it had become common.

Europeans did not begin to use the compass until the end of the 13th century on major maritime expeditions. Arab sailors apparently learned of the compass from Europeans, adopting its use in the first half of the 14th century. Around about 1358, there is a story about an English monk by the name of Nicholas de Lynne, who worked on an Arab ship as a navigator due to his skill and knowledge of "the magnetic compass" (see lnventio Fortunata).

Before the introduction of the compass, navigation at sea was mainly done by the stars, supplemented in a few places by the use of soundings. Difficulties arose when the sea was too deep for soundings and/or conditions were continually overcast or foggy. So the adoption of the compass was not the same everywhere.

For example, the Arabs could generally rely on clear skies to navigate the Persian Gulf and the Indian Ocean (they also knew the predictable nature of monsoons), which may partly explain their relatively late adoption of the compass. Sailors in the relatively shallow Baltic Sea mostly used soundings. In the Mediterranean basin, the season for sea travel lasted only from April to October, due in part to the lack of safe clear skies during the Mediterranean winter and the sea being far too deep for surveys. With improvements in dead reckoning methods and the development of better maps, this changed during the second half of the 13th century (see Chapter 3). Around 1290, the travel season could begin as early as January or February and ended in December. The additional months were of considerable economic importance; e.g., they allowed the Venetian convoys to make two round trips per year in the eastern Mediterranean instead of one. At the same time, traffic between the Mediterranean and Northern Europe grew, and one factor that perhaps played a role was the newly adopted compass which made crossing the Bay of Biscay safer and easier.

Note: The location and (slow) movements of the magnetic North Pole are due to movements of the Earth's ferrous core (~ 40 km / year). Since 2005, it is located in Canada but lately it has been drifting faster. While it drifted with a velocity of about 15 km/year in the 1990s, it now has a drift velocity of ~ 55km/year. At present, it is over the Arctic Ocean but in less than 50 years it is expected to be located in Siberia.

CHAPTER 2 – MAPPING

1) On land – reminders

Latitude is an angle expressed in degrees north or south (of the equator) and denotes the location of a point on Earth (or on another planet). The latitude varies between 0° at the equator and 90° at the poles.

Longitude is an angle expressed in degrees east or west (of the prime meridian) and denotes the location of a point on Earth (or another planet). All points of the same longitude belong to a line that follows the curvature of the earth, intersects the equator at a right angle, and connects the North Pole to the South Pole. This line is called a meridian. Unlike latitude (north-south position) which uses the equator and poles as references, no natural reference exists for longitude; we therefore need to define a reference (or prime) meridian which currently goes through Greenwich, UK. Longitude, generally denoted as λ, is therefore an angular measurement over 360 ° with respect to a reference meridian and ranges from +180° to -180° or 180° West to 180° East.

Choosing the prime meridian

Until universally adopting the Greenwich meridian in 1884, each country had its own prime meridian. In France, the obligation to use the Greenwich meridian was the subject of a ministerial decision in 1913. Regarding standardized time, France only adopted UTC (formerly GMT or Greenwich mean time) on August 9, 1978 (!) and until then would still use its own legal standard while referring to Greenwich mean time as "Paris mean time, retarded by 9 minutes and 21 seconds".

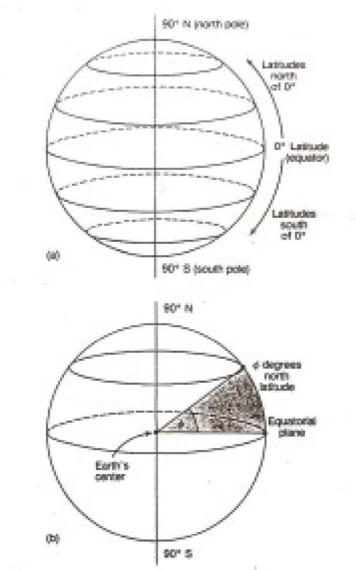


Figure 1.5

(a) Latitude lines are drawn parallel to the equatorial plane. (b) The value of a latitude line is expressed in angular degrees determined by the angle formed between the equatorial plane and the latitude line to the earth's center. This is the angle ϕ (phi). The degree value of ϕ must be noted as north or south of the equator.

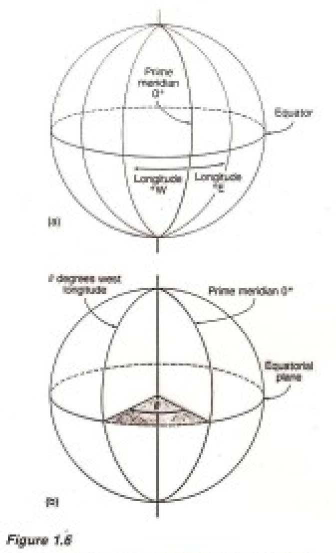
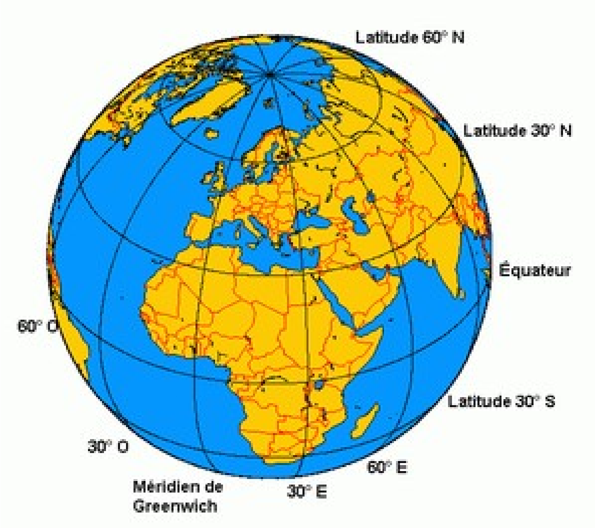


Figure 1.6

(a) Longitude lines are drawn with reference to the prime meridian. (b) The value of a longitude line is expressed in angular degrees determined by the angle formed between the prime meridian and the longitude line to the earth's center. This is the angle θ (theta). The value of θ is given in degrees east or west of the prime meridian.



Latitudes and longitudes intersect at right angles (https://en.wikipedia.org/wiki/Meridian_(geography))

2) **Map projections** [adapted from: https://en.wikipedia.org/wiki/Map_projection]

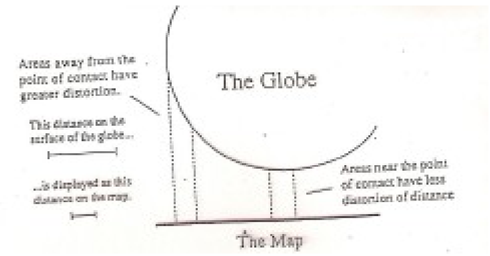
In cartography, a map projection is a way to flatten a globe's surface into a plane in order to make a map. This requires a systematic transformation of the latitudes and longitudes of locations from the surface of the globe into locations on a plane.

All projections of a sphere onto a plane necessarily distort the surface in some way and to some extent. Depending on the purpose of the map, some distortions are acceptable and others are not; therefore, different map projections exist in order to preserve some properties of the sphere-like body at the expense of other properties. The study of map projections is primarily about the characterization of their distortions. There is no limit to the number of possible map projections. Projections are a subject of several pure mathematical fields, including differential geometry, projective geometry, and manifolds. However, "map projection" refers specifically to a cartographic projection.

From a mathematical point of view, a projection makes it possible to establish a correspondence between the surface of the spherical Earth and the plane (or otherwise developed) surface such as:

$$x = f_1(\varphi, \lambda)_{\text{et}}\ y = f_2(\varphi, \lambda)$$

where x,y denote the planar coordinates, φ the latitude, λ the longitude, and f_1,f_2 are functions to achieve the coordinate transformation that are continuous everywhere on the starting set except on a small number of lines and points (such as poles). There exist therefore an infinite number of solutions (projections) and mathematicians have not been holding back in finding them, as we now know of more than two hundred solutions (Joly, 1985, page 39).

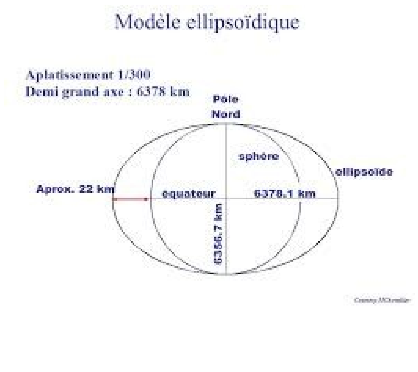
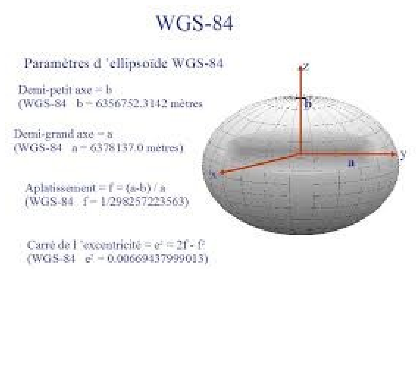
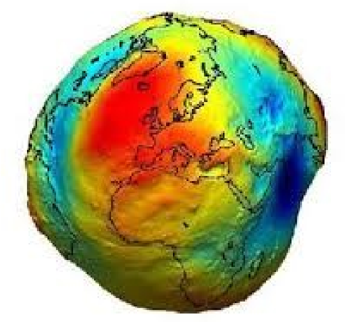


From globe to map

Projections are based on spheres or ellipsoids. In order to project the Earth, being slightly irregularly shaped, one starts by choosing a representative ellipsoid of the geoid. There are several ellipsoids in use, the most common being the WGS 84 (World Geodetic System set up in 84).

> Reminder:
> A geoid is an equipotential reference surface of the Earth's gravity field.
>
> The reference geoid is based on the marine geoid, i.e., the average shape that the ocean surface would take under the influence of Earth's gravity alone, including gravitational attraction and the Earth's rotation, but excluding other factors such as winds and tides. According to the laws of hydrostatics this is about equivalent to an equipotential surface. The continuation of the marine geoid is called the continental geoid. The resulting reference geoid has the shape of an ellipsoid, slightly deformed, flattened at the poles by about 0.335%. It is a more accurate representation of the Earth's surface than the spherical or ellipsoidal approximation.

However, in cartography we must use an ellipsoid, even if it represents the earth less well than the geoid, simply because it can be represented by a mathematical formula. In addition, the ellipsoid alone is not enough: it is necessary to position it in relation to the real surface of the Earth. The data of the ellipsoid and of the positioning parameters constitutes what is called a "geodetic datum" to which a projection can be applied.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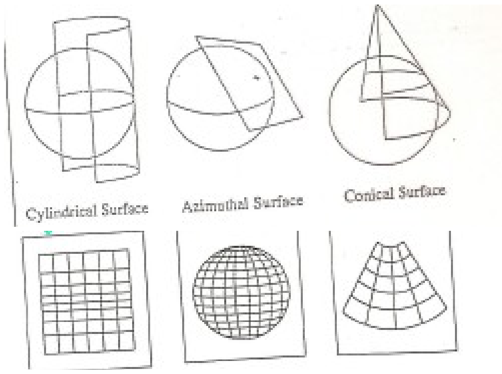
Types of projections and their properties

Once a datum is fixed, we can choose and apply the type of projection in order to obtain a map.

A surface that can be unfolded or unrolled into a plane or sheet without stretching, tearing or shrinking is called a developable surface. The cylinder, cone and the plane are all developable surfaces. The sphere and ellipsoid do not have developable surfaces, so any projection of them onto a plane will have to distort the image.

There are three developable surfaces (plane, cylinder, cone) that give rise to three main types of projections:

- the cylindrical projection;
- the conical projection;
- the azimuthal projection.



The choice of which projection to use depends on the application as each projection has **different properties**:

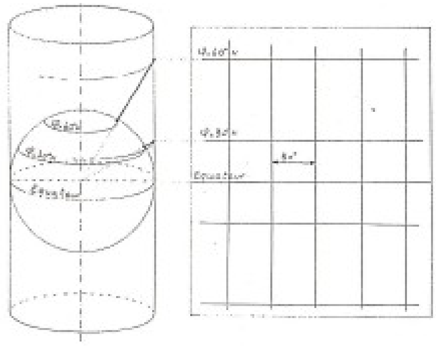
- an **equivalent** (or equal-area) projection preserves the surface areas;
- a **conformal projection** preserves shapes locally;
- an **equidistant** projection preserves the distances along lines of longitude.

No single projection can simultaneously be conformal and equivalent.

A projection is called **aphylactic** if it is neither conformal nor equivalent: but it can still be equidistant. Its name derives from phyla (Greek for: I keep, I preserve, hence aphyla meaning I do not preserve) owing to the fact that it neither preserves the angles (or shapes, i.e., non conformal) nor the surface areas (non equivalent).

A projection that cannot be classified as one of these three types is called individual or unique. A projection can also be "interrupted".

I) Cylindrical Projection



Projection cylindrique

The ellipsoid is projected onto a cylinder that is wrapped around it. Once the cylinder is unrolled, one obtains a map where meridians are mapped to equally spaced vertical lines and circles of latitude (parallels) are mapped to horizontal lines.

Examples of cylindrical projections:

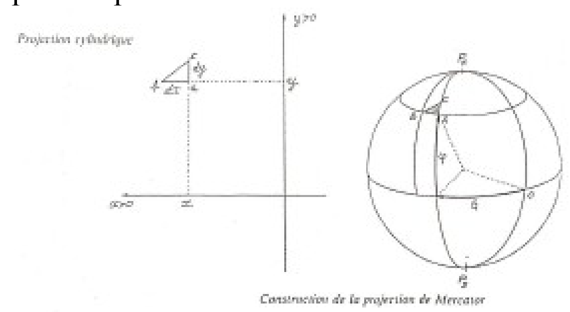
- Mercator Projection (conformal)
- Peters Projection (equivalent)
- Robinson Projection (pseudo-cylindrical, aphylactic)
- UTM Projection also know as Gauss-Kruger (conformal)
- Cylindrical equidistant projection
- Oblique Mercator Projection (used in Switzerland for instance).

Supplement one the Mercator projection

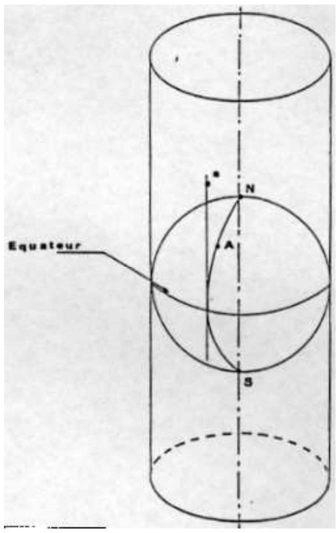
It is a cylindrical map projection presented by Flemish geographer and cartographer Gerardus Mercator in 1569. It became the standard map projection for navigation because it is unique in representing north as up and south as down everywhere while preserving local directions and shapes. The map is thereby conformal. As a side effect, the Mercator projection inflates the size of objects away from the equator. This inflation is very small near the equator but accelerates with increasing latitude to become infinite at the poles. As a result, landmasses such as Greenland and

Antarctica appear far larger than they actually are relative to landmasses near the equator, such as Central Africa.

The fact that a straight line on a Mercator map corresponds to a line of constant azimuth made it particularly useful to sailors, even if the path thus defined is generally not along a great circle and therefore not the shortest path. In the days of tall sailing ships, the length of the voyage was subject to the elements, and therefore the distance of the trip was less important than the direction, mainly because the longitude was difficult to determine precisely.

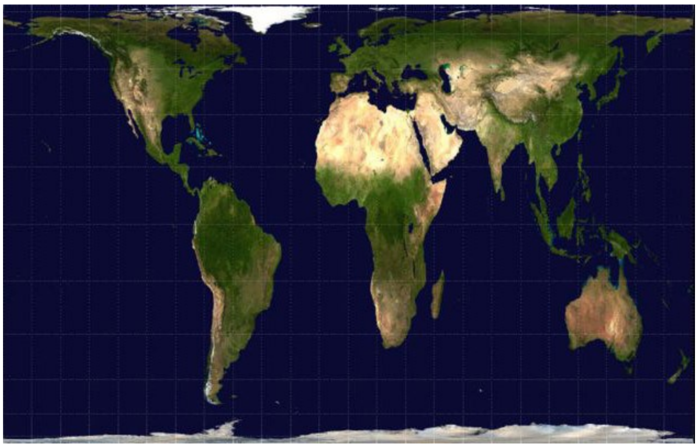


The main fault of the traditional maps inspired by Mercator's work intended for navigation is that they give us an erroneous idea of the areas occupied by the different regions of the world, and therefore of the relationships between peoples. Some examples: South America seems smaller than Greenland while, in reality, it is nine times larger: 17.8 million km² vs 2.1 million km²; India (3.3 million km²) seems smaller than Scandinavia (Norway + Sweden + Finland = 0.8 million km²). Europe (9.7 million km²) seems larger than South America, although the latter is almost twice the size of Europe.



Projection de Mercator (http://membres.lycos.fr/smeys/projec.htm)

Another type of cylindrical projection: The Gall–Peters Projection (http://en.wikipedia.org/wiki/Gall-Peters_projection)



The Gall–Peters projection is a rectangular map projection that maps all areas such that they have the correct sizes relative to each other. Like any equal-area projection, it achieves this goal by distorting most shapes. The projection is a particular example of the cylindrical equal-area projection with latitudes 45° north and south as the regions on the map that have no distortion.

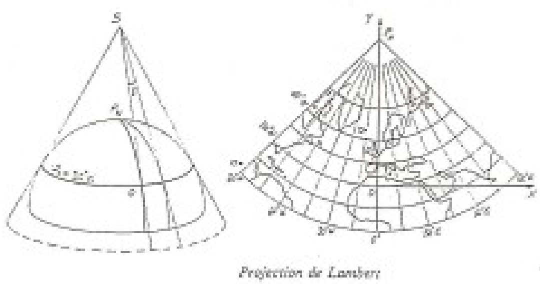
The Gall–Peters projection achieved notoriety in the late 20th century as the centerpiece of a controversy about the political implications of map design.

II) Conical Projection

The ellipsoid is projected onto a cone that has an arbitrary parallel as tangent line or that intersects the globe at two secant lines. The resulting conic map is obtained by unrolling the cone and is characterised by low distortion in scale, shape, and area near those standard parallels.

Example

Lambert conformal conic Projection



III) Azimuthal Projection

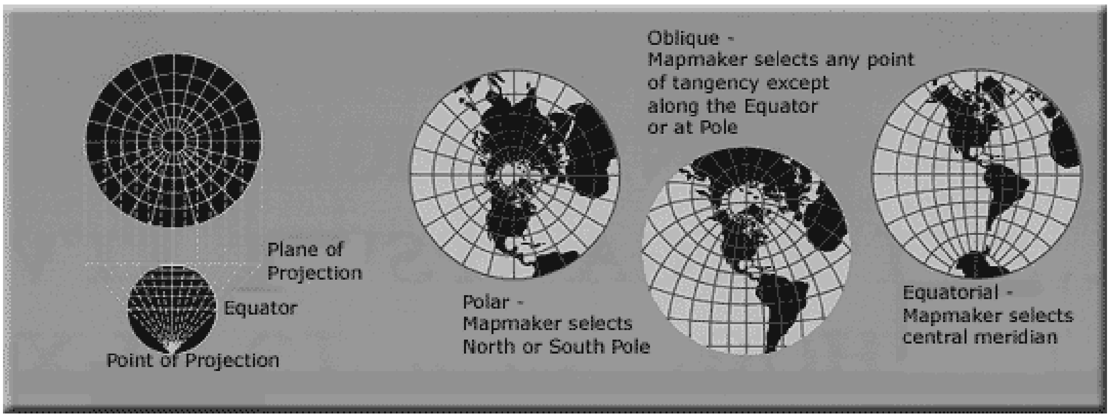
The ellipsoid is projected onto a plane surface that is tangential at one point or intersects the globe along a circle.

There are three types of azimuthal projections, which differ in the position of the perspective point used for the projection:

- stereographic projection;
- gnomonic projection;
- orthographic projection.

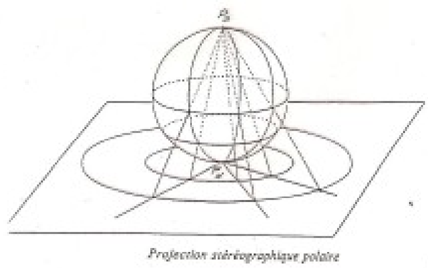
Moreover, depending on the position of the tangent plane, the azimuthal projection is said to be *polar* (plane tangent to a pole), *equatorial* (plane tangent to a point on the equator), or *oblique* (plane tangent to another point). The polar azimuthal projection is used for air traffic routes passing through polar regions to reduce travel distance.

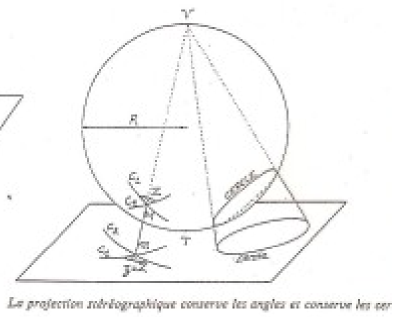
III a) Stereographic Projection



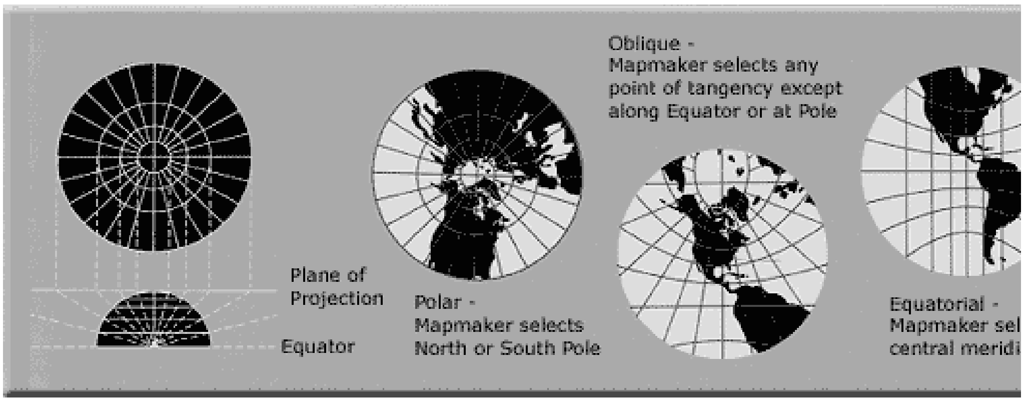
http://egsc.usgs.gov/isb/pubs/MapProjections/projections.html#stereographic

The perspective point is placed on the spheroid or ellipsoid opposite to the projection plane. The plane of projection that separates the northern and southern hemispheres is called the equatorial plane.

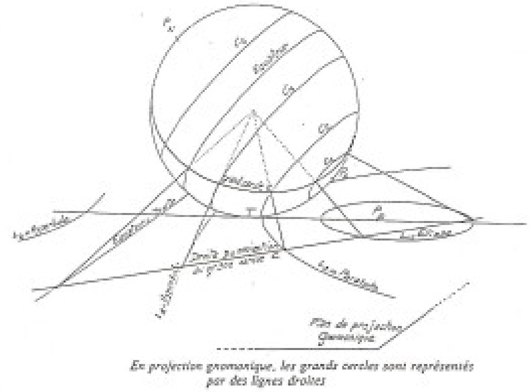




III b) Gnomonic Projection

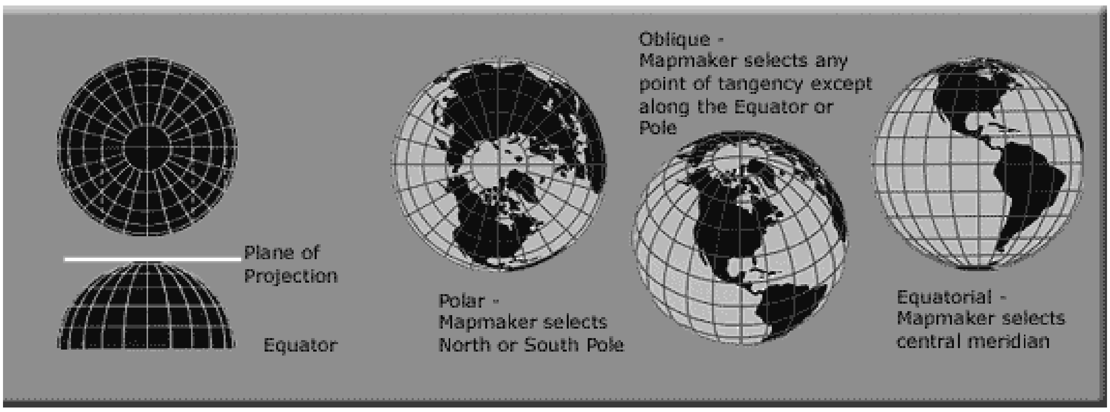


http://egsc.usgs.gov/isb/pubs/MapProjections/projections.html#gnomonic



The point of perspective is at the centre of the spheroid. The gnomonic projection displays all great circles as straight lines, resulting in any straight line segment on a gnomonic map showing a geodesic, the shortest route between the segment's two endpoints.

III c) Orthographic Projection



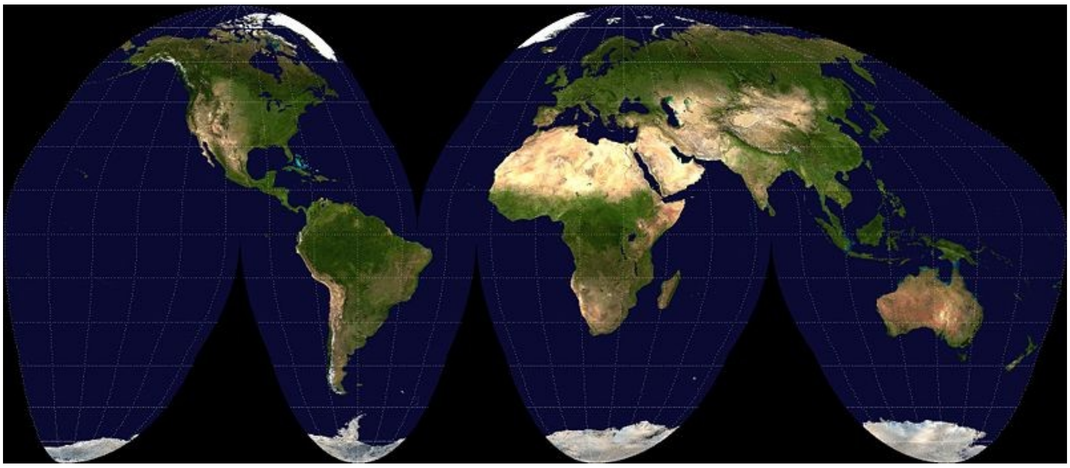
http://egsc.usgs.gov/isb/pubs/MapProjections/projections.html#orthographic

The point of perspective is at an infinite distance. We perceive a hemisphere of the globe as if we were located in space. Surfaces and shapes are distorted, but distances are preserved on parallel lines.

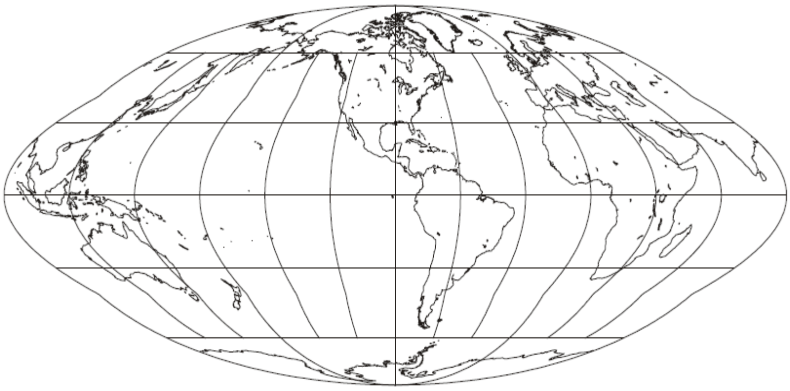
Interrupted Projections (or composite maps)

An interrupted projection is a projection in which the projection surface is not a continuous rectangle but a where the globe has been split. This interruption serves the purpose of reducing distortions, which means that the shape of the continents is often very close to reality, although the "gaps" they contain make them useless for navigation.

Goode Projection: an interrupted, pseudocylindrical, equal-area, composite map projection
http://www.cosmovisions.com/qMondeGoodeHomolosineTopo.htm
http://en.wikipedia.org/wiki/Image:Goode-homolosine-projection.jpg



Homolosine Projection
A map of the Earth's surface projected on a basis of sine curves, with breaks across the oceans so that the continents appear with the least amount of distortion and with a constant size ratio between them. This map represents a global view of the world, with uninterrupted land masses except Antarctica and Greenland. Distances and directions are not precise everywhere. (adapted from The Free Dictionary: http://www.thefreedictionary.com/homolosine+projection)



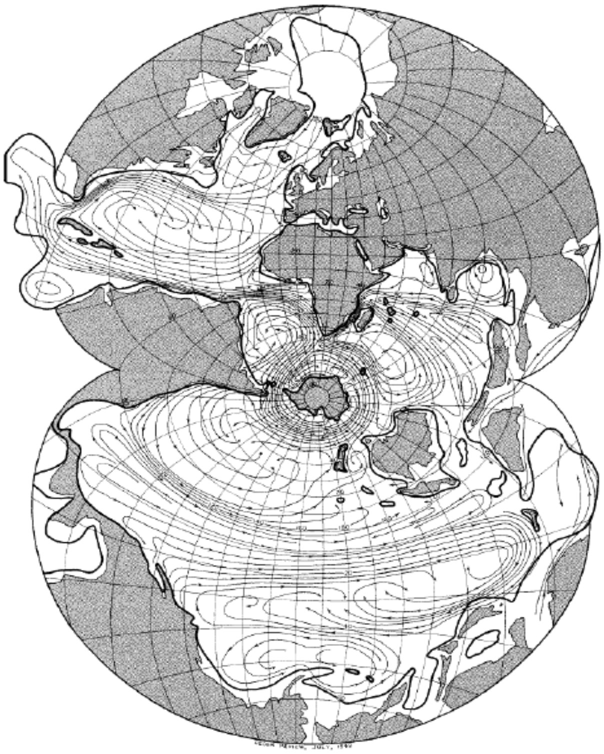
Goode Homolosine;
Fusion of Mollweide and Sinusoidal;
Pseudocylindrical; Equal-area;
J. Paul Goode; 1923

August's Projection
Conformal (preserved angles)

Surface currents in winter for the Northern Hemisphere

___ 200 m

Maps of the Whole World Ocean
Athelstan F. Spilhaus
Geographical Review
Vol. 32, No. 3 (Jul., 1942)

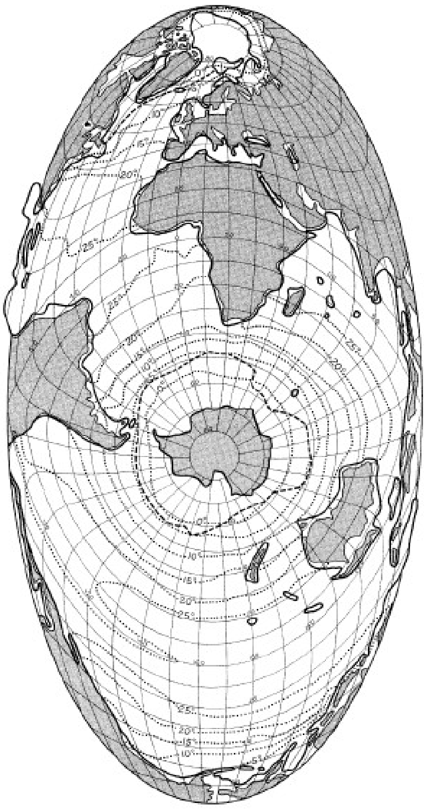


Aitoff Projection
Equivalent (preserved surface areas)

Mean T
--- ice line

___ 200 m

Maps of the Whole World Ocean
Athelstan F. Spilhaus
Geographical Review
Vol. 32, No. 3 (Jul., 1942)



More recently, efforts have been made with **polyhedral projections** with a high number of polyhedra. The AuthaGraph (see below) is currently considered the “best map in the world”.

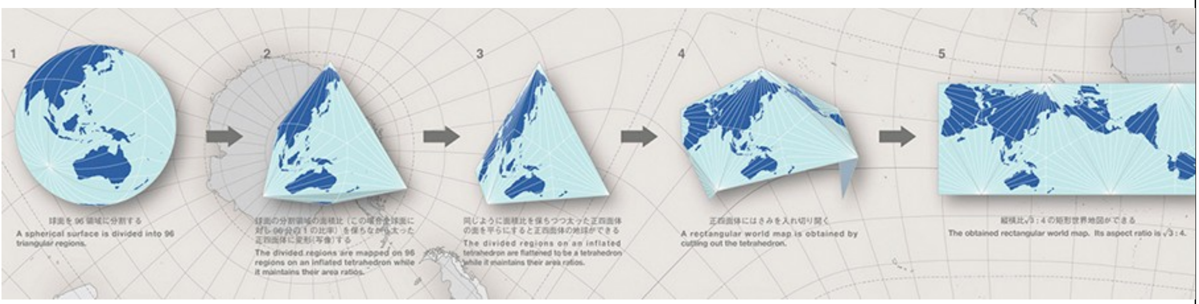
(adapted from https://en.wikipedia.org/wiki/AuthaGraph_projection)
AuthaGraph is an approximately equal-area world map projection invented by Japanese architect Hajime Narukawa in 1999. The map is made by equally dividing a spherical surface into 96 triangles, transferring it to a tetrahedron while maintaining area proportions and unfolding it onto a rectangle: it is a polyhedral map projection. **The map substantially preserves sizes and shapes of all continents and oceans while it reduces distortions of their shapes**, as inspired by the Dymaxion map. Triangular world maps are also possible using the same method. The name is derived from "authalic" (from Greek αὐτός (autós, “same”) + αἶλος (aîlos, “area”)) and "graph".

The method used to construct the projection ensures that the 96 regions of the sphere that are used to define the projection each have the **correct area**, but the projection does not qualify as equal-area because the method does not control area at infinitesimal scales or even within those regions.

The AuthaGraph world map can be tiled in any direction without visible seams. From this map-tiling, a new world map with triangular, rectangular or a parallelogram's outline can be framed with various regions at its centre. This tessellation allows for depicting temporal themes, such as a satellite's long-term movement around the earth in a continuous line. This map provides a decentralized world view. The map projection attempts to reflect a multilateral perspective for a better understanding of the global phenomena of the 21st century.

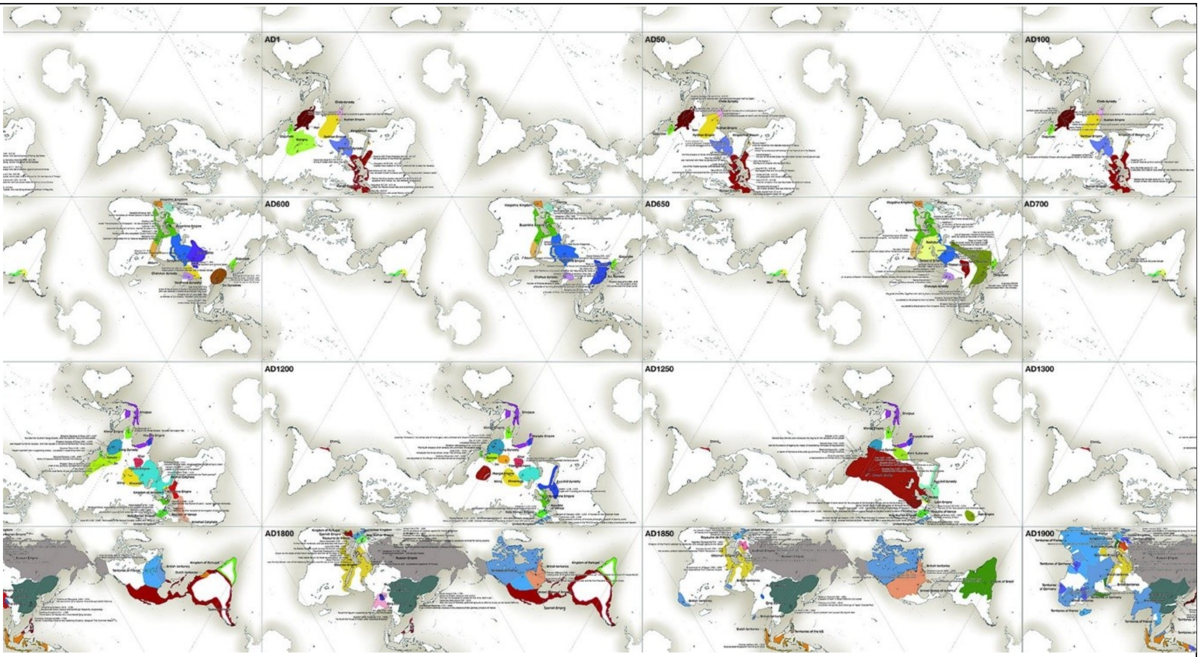
In 2011 the AuthaGraph mapping projection was selected by the Japanese National Museum of Emerging Science and Innovation (Miraikan) as its official mapping tool. Since 2015 it is used in official Japanese school books.

https://en.wikipedia.org/wiki/AuthaGraph_projection

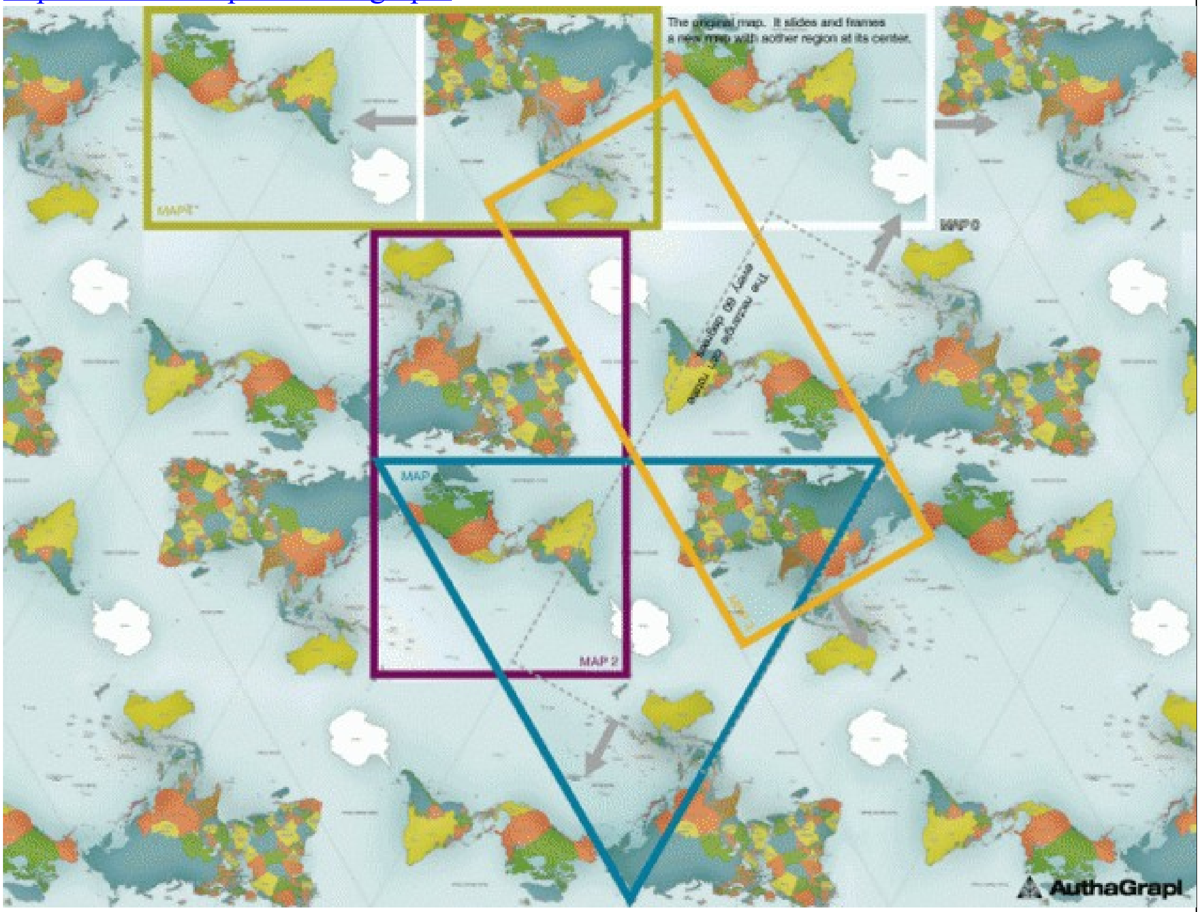


https://www.gunesintamicinde.com/yalandan-arindirilmis-bir-dunya-haritasi-authagraph-world-map/

Steps: 1) cut the glove into 96 equal-sized areas; 2) transfer the 96 regions onto an “inflated tetrahedron”, a cross between a sphere and a pyramid, made of 4 nested cones; there are deformations but the relationships between the surfaces do not change; 3) flatten the faces of the tetrahedron (again, without changing the ratios between surfaces); 4) cut and flatten the tetrahedron to obtain a rectangle: the AuthaGraph.



https://wrocenter.pl/en/authagraph/



https://www.vice.com/en_us/article/vvy9e8/escher-world-map-wins-good-design-award

Summary of map projections and their main properties

	Map Projections
Cylindrical	• Conformal: Mercator • Equidistant: Cassini, Aphylactic • Equivalent: Peters, Lambert • Compromise: Gall, Miller
Pseudo-cylindrical	• Equivalent: Eckert I, Eckert II, Eckert IV, Equal Earth, Collignon, Goode, Mollweide, Sinusoidal (Sanson-Flamsteed), Tobler • Compromise: Kavrayskiy VII, Robinson, Wagner VI
Conic	• Conformal: Lambert • Equivalent: Albers
Pseudo-conic	Equivalent: Bonne, Bottomley, Werner
Azimuthal	• Conformal: Stereographic • Equidistant: Postel • Equivalent : Lambert, Gnomonic, Orthographic
Pseudo-azimuthal	Compromise: Aitoff, Winkel-Tripel
Polyhedral	Compromise: AuthaGraph, Fuller, Octant

We especially appreciate our "**planetary ocean**" (see Figure 1.3 in the book of the same title by Michèle Fieux, 2009, my oceanography teacher at ENSTA). Reproduction (see below) courtesy Michèle Fieux and ENSTA Press.

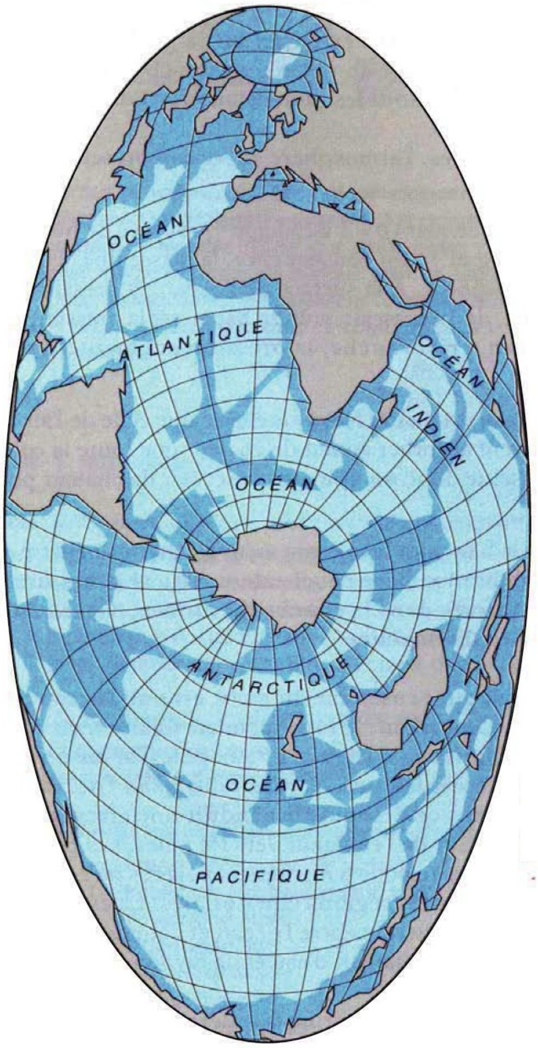


Figure 1.3 View of the Earth showing the continuity of the planetary ocean (depths greater than 4000m are in light blue) - after Tchernia, 1978, according to an illustration by WHOI.

Other well documented sites:

- USGS - http://egsc.usgs.gov/isb/pubs/MapProjections/projections.html#globe; with illustrations of all projections
- Details about all possible and imaginable projections

http://acdsweb.free.fr/textes/Davidowicz_projection-carto.html

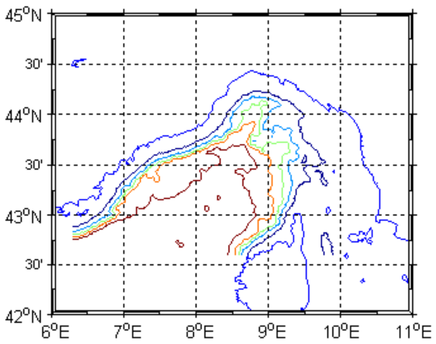
Matlab tools to create these projections: M_Map, free download from

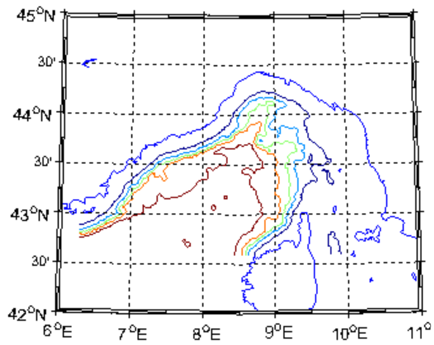
http://www.eos.ubc.ca/~rich/#M_Map

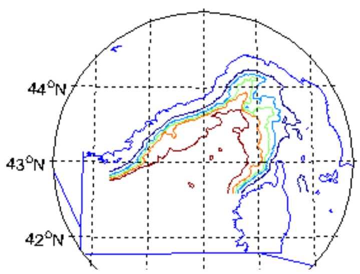
Ligurian Sea plotted with the following map projections:

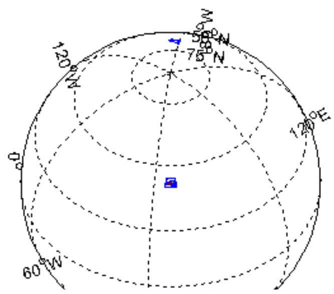
Upper left: Mercator

upper right: Lambert









Lower left: Stereographic

lower right: orthographic

%%%%%%%%%%%%%%%%%%%%%%%%%%

PYTHON TOOLS:

for python, Geopandas:

https://geopandas.org/gallery/index.html

Adding a background map to plots
../_images/sphx_glr_create_geopandas_from_pandas_thumb.png

Creating a GeoDataFrame from a DataFrame with coordinates
../_images/sphx_glr_plotting_with_geoplot_thumb.png

Plotting with Geoplot and GeoPandas
../_images/sphx_glr_plot_clip_thumb.png

Clip Vector Data with GeoPandas
../_images/sphx_glr_cartopy_convert_thumb.png

Plotting with CartoPy and GeoPandas

%%%%
For further manipulation of vector data, use shapely.

https://pypi.org/project/Shapely/
%%

Appendices:

* Article in Le Monde newspaper on the importance of projections

http://www.lemonde.fr/les-decodeurs/article/2015/10/20/pourquoi-les-cartes-geographiques-sont-mensongeres_4793301_4355770.html pour 2005.

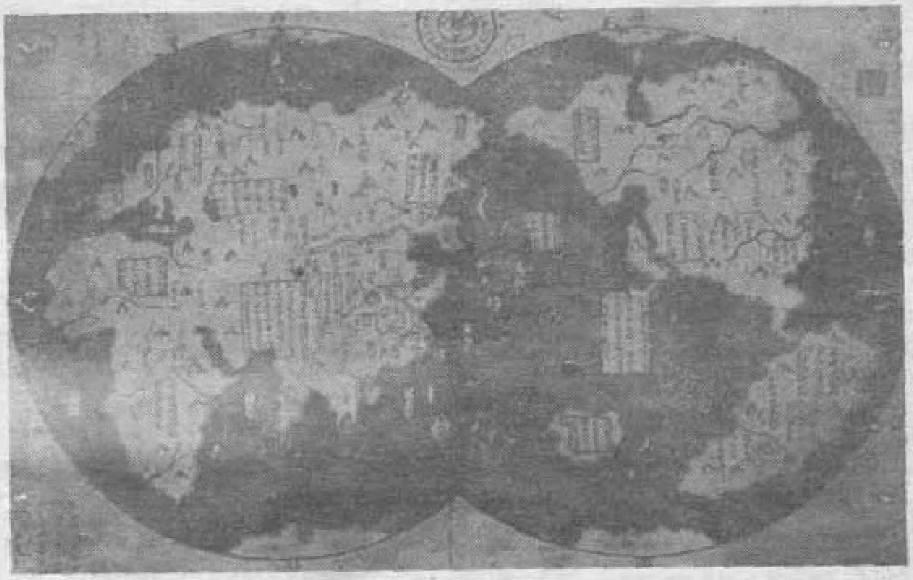
Marseille Plus 20 Janvier 2006

Christophe Colomb détrôné ?

HISTOIRE

LES CHINOIS AURAIENT DÉCOUVERT L'AMÉRIQUE AVANT L'EXPLORATEUR

Gavin Menzies, historien amateur - britannique, défend la thèse de la découverte de l'Amérique par les Chinois. Il a d'ailleurs popularisé cette idée en publiant un best-seller en 2002. Aujourd'hui, cet ancien de la royal navy, affirme détenir une nouvelle preuve, une carte chinoise datant du XVe siècle. Cette dernière date la découverte du nouveau monde en 1421 soit 70 ans avant Christophe Colomb. Cependant les milieux académiques restent sceptiques suites aux invraisemblances décelées par les spécialistes chinois. Dans un premier temps, les experts ont constaté que la cartographie de la carte n'a aucun rapport avec celle de l'époque, à cela s'ajoutent des caractères qui n'existaient pas encore pendant cette période.



Les expéditions de Zheng He (1405 et 1432) ne l'auraient mené qu'en Afrique. Cette carte dévoile une autre version. Photo AFP