Welcome to Geodesy

Geodesy is the science of measuring and monitoring the size and shape of the Earth and the location of points on its surface. NOAA's National Geodetic Survey (NGS) is responsible for the development and maintenance of a national geodetic data system that is used for navigation, communication systems, and mapping and charting.

Members of a 1922 geodetic survey expedition. **Click on the image** for larger view.

In this subject, you will find three sections devoted to learning about geodesy: an online tutorial, an educational roadmap to resources, and formal lesson plans.

The Geodesy Tutorial is an overview of the history, essential elements, and modern methods of geodesy. The tutorial is content rich and easy to understand. It is made up of 10 chapters or pages (plus a reference page) that can be read in sequence by clicking on the arrows at the top or bottom of each chapter page. The tutorial includes many illustrations and interactive graphics to visually enhance the text.

The Roadmap to Resources complements the information in the tutorial. The roadmap directs you to specific geodetic data offered by NOS and NOAA.

The Lesson Plans integrate information presented in the tutorial with data offerings from the roadmap. These lesson plans have been developed for students in grades 9–12 and focus on the importance of geodesy and its practical application, including what a datum is, how a datum of reference points may be used to describe a location, and how geodesy is used to measure movement in the Earth's crust from seismic activity.

SCILINKS Selected by Science Educators from NSTA

The National Science Teachers Association (NSTA) has included this online resource in its *SciLinks* database. *SciLinks* provide students and teachers access to Web-based, educationally appropriate science content that has been formally evaluated by master teachers.

For more information about the *SciLinks* evaluation criteria, click here: http://www.scilinks.org/certificate.asp.

To go directly to the *SciLinks* log-on page, click here: http://www.scilinks.org/.

(top)

○ This site ○ NOAA search

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

The Global Positioning System

CORS and GIS

References

noaa ocean service education

◀ Back ◀

Welcome to Geodesy

Members of a 1922 geodetic survey expedition. Until recent advances in satellite technology, namely the creation of the Global Positioning System (GPS), geodetic surveying was an arduous task best suited to individuals with strong constitutions, and a sense of adventure.

Geodesy

What is Geodesy?

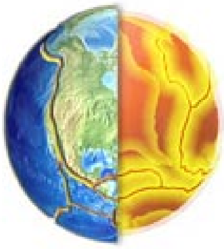
◀ ▶

Using spatial reference systems created by geodesists, any location on the Earth can be located quickly and accurately. ***Click on the image*** *for an animated view.*

Geodesy is the science of measuring and monitoring the size and shape of the Earth. Geodesists basically assign addresses to points all over the Earth. If you were to stick pins in a model of the Earth and then give each of those pins an address, then you would be doing what a geodesist does. By looking at the height, angles, and distances between these locations, geodesists create a spatial reference system that everyone can use.

Building roads and bridges, conducting land surveys, and making maps are some of the important activities that depend on a spatial reference system. For example, if you build a bridge, you need to know where to start on both sides of the river. If you don't, your bridge may not meet in the middle.

As positioning and navigation have become fundamental to the functions of society, geodesy has become increasingly important.



The earth's crust is made of up separate plates that ride atop a sea of magma. These plates are constantly shifting and interacting. **Click on the image** for an animated view.

Geodesy helps the transportation industry ensure safety and reliability, while reducing costs. Without geodesy, planes might land next to -- rather than at -- airports, and ships could crash onto land. Geodesy also helps shipping companies save time and money by shortening their ships' and airplanes' routes and reducing fuel consumption.

Geologists, oceanographers, meteorologists, and even paleontologists use geodesy to understand physical processes on, above, and within the Earth. Because geodesy makes extremely accurate measurements (to the centimeter level), scientists can use its results to determine exactly how much the Earth's surface has changed over very short and very long periods of time (Careers in Geodesy, 1986).

The Earth's surface changes for many reasons. For instance, its surface rises and falls about 30 centimeters (about 1 foot) every day due to the gravitational influences of the moon and the sun. The Earth's outermost layer, the crust, is made up of a dozen or more "plates" that ride atop a sea of molten rock, called magma, which flows beneath the surface of the Earth.

Plate tectonics is the scientific discipline that looks at how these plates shift and interact, especially in relation to earthquakes and volcanoes. Although these phenomena are violent and usually affect large areas of land, even smaller events, such as erosion and storms, have an impact on shaping the Earth's surface. Geodesy helps us determine exactly where and how much the Earth's surface is changing.

(top)

◀ ▶

search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

The Global Positioning System

CORS and GIS

References

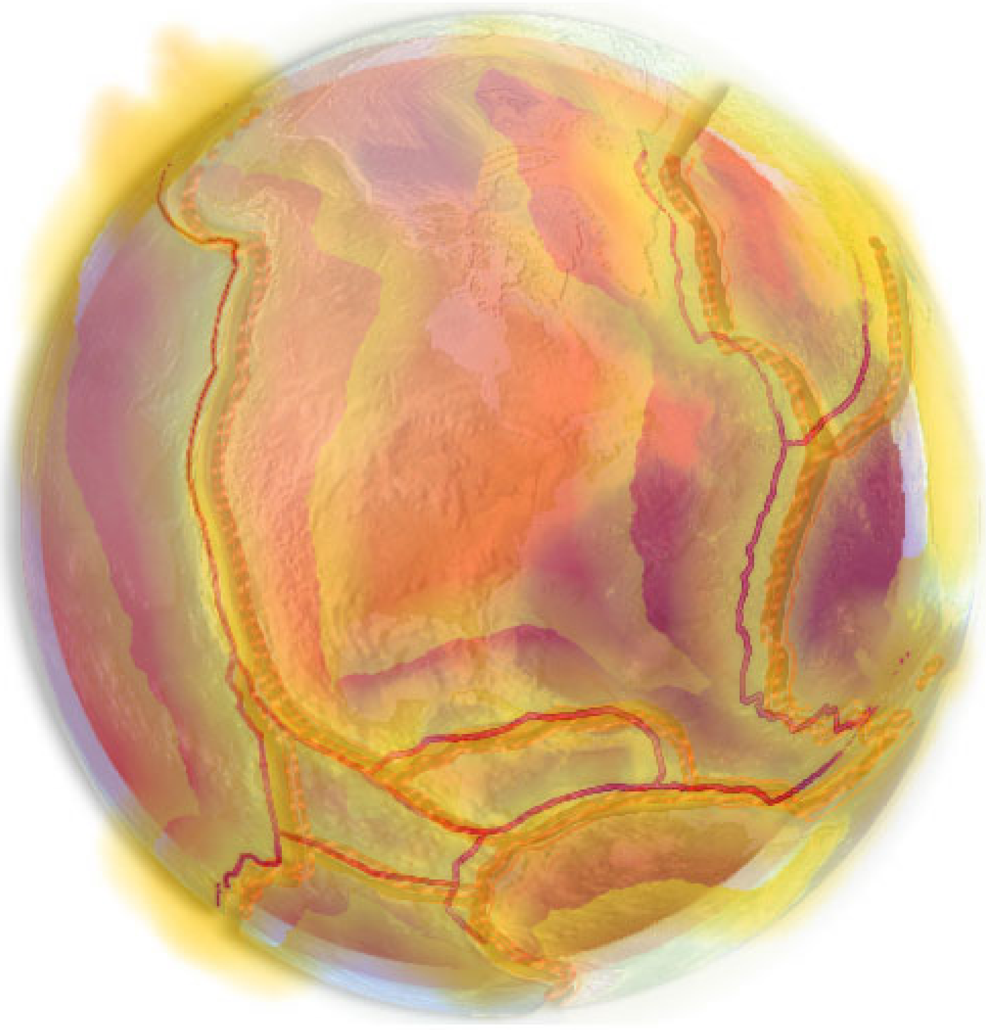
Return to **What is Geodesy**

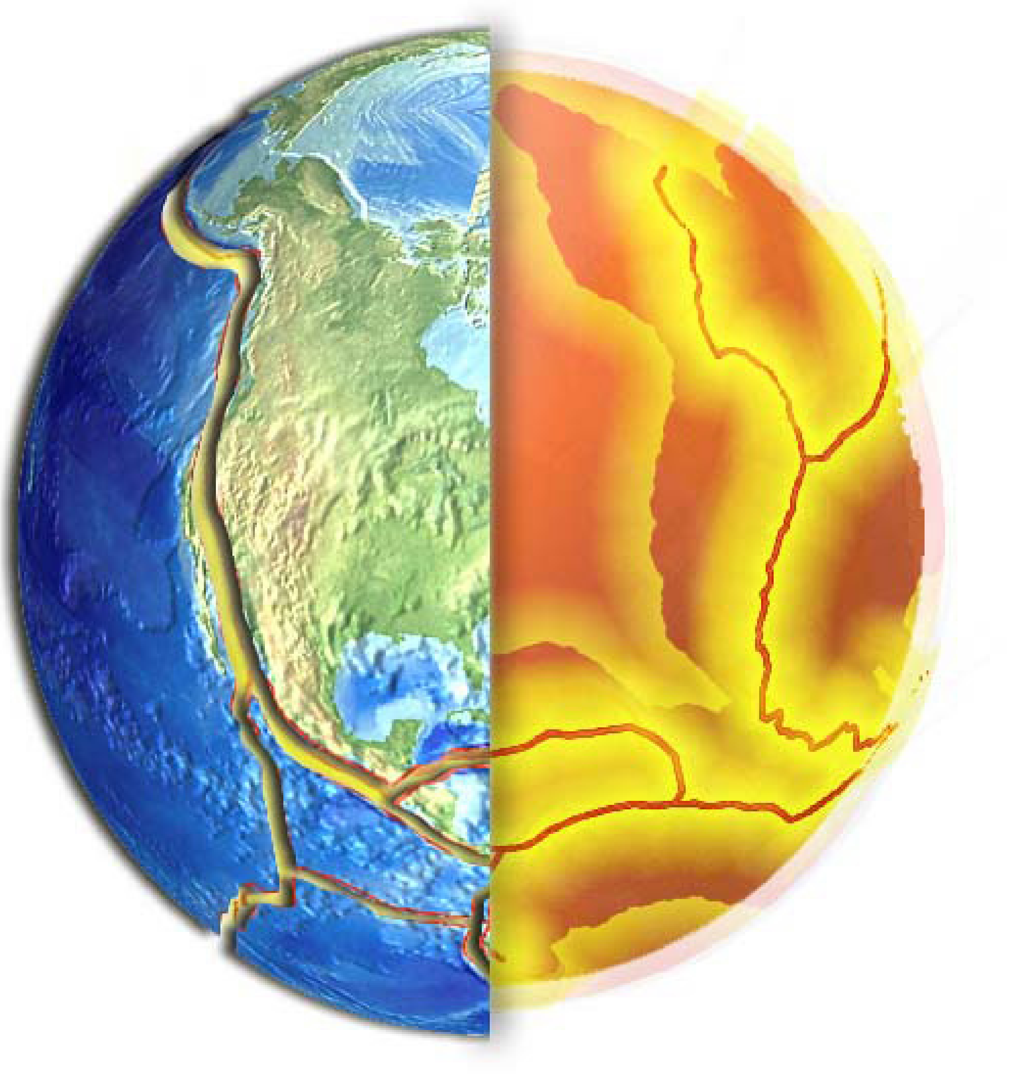
Through the use of spatial reference systems created by geodesists any location on the Earth can be located quickly and accurately. (Image Source: ETOPO2 global elevation data). **Animated version.**

(top)

Return to What is Geodesy

The earth's crust is made of up separate plates that ride atop a sea of magma. These plates are constantly shifting and interacting. The phenomena that affect the size and shape of the Earth's continents and ocean basins are subtle and occur over hundreds of thousands of years. (Image source: GIS-based plate boundaries, ETOPO2 global elevation data). **Animated version**.





(top)

Geodesy

The History of Geodesy

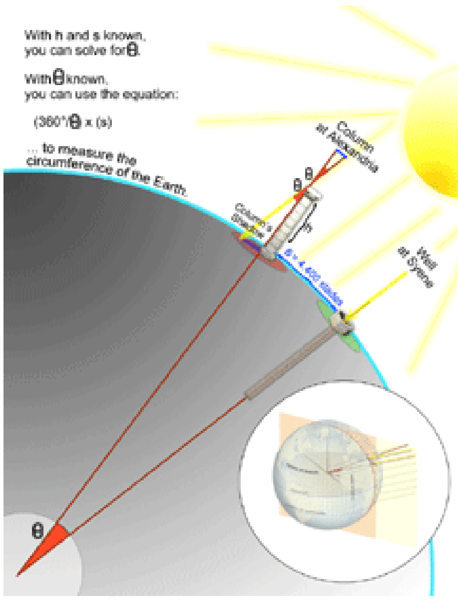
◀ ▶

Throughout history, the shape of the Earth has been debated by scientists and philosophers. By 500 B.C. most scholars thought the Earth was completely spherical. The Greek philosopher Aristotle (384-322 B.C.) is credited as the first person to try and calculate the size of the Earth by determining its circumference (the length around the equator) He estimated this distance to be 400,000 stades (a stadia is a Greek measurement equaling about 600 feet). With one mile equal to 5,280 feet, Aristotle calculated the distance around the Earth to be about 45,500 miles (Smith, 1988).

Around 250 B.C., another Greek philosopher, Eratosthenes, measured the circumference of the Earth using the following equation:

(360° ÷ θ) x (s)

In this calculation, (s) is the distance between two points that lie north and south of each other on the surface of the Earth. If you were to draw a line from each of these points to the center of the Earth, the angle formed between them would be θ.

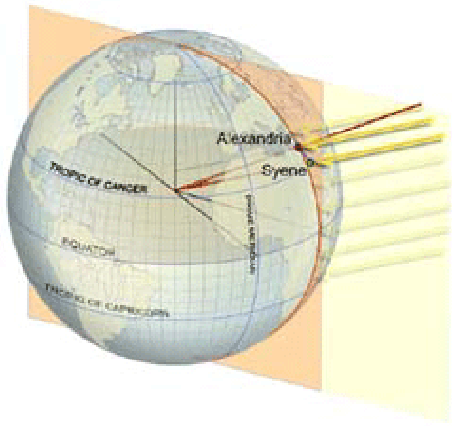


An illustration of how Eratosthenes actually calculated the circumference of the Earth. ***Click on the image*** *for larger view.*

Obviously, Eratosthenes could not go to the center of the Earth, so he got the angle measurement using the rays of the sun. At noon on the longest day of the year, the summer solstice, the sun shone directly into a deep well at Syene (which is now Aswan, Egypt), casting no shadow.

At the same time in Alexandria, Egypt, he found that the sun cast a shadow equivalent to about 1/50th of a circle or 7.12°. Eratosthenes combined this measurement with the distance between Syene and Alexandria, about 4,400 stades.

If we plug these numbers into the above equation, we get: (360°÷ 7.12°) which equals 50; and 50 x 4,400 equals 220,000 stades, or about 25,000 miles. The accepted measurement of the Earth's circumference today is about 24,855 miles (Smith, 1988). Given the simple tools and technology that Eratosthenes had at his disposal over 2,000 years ago, his calculations were quite remarkable.



Eratosthenes calculations were based on the assumption that Syene lay on the Tropic of Cancer and that Alexandria lay directly north of Syene on exactly the same line of longitude. ***Click on the image*** *for larger view.*

As technology developed, scientists and surveyors began to use different techniques to measure distance. In the 16th and 17th centuries, triangulation started to be used widely. Triangulation is a method of determining the position of a fixed point by measuring the angles to it from two other fixed

search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

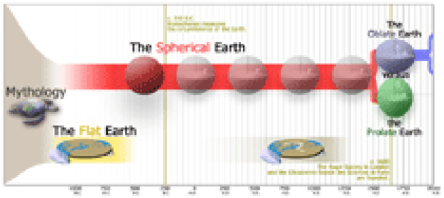
The National Spatial Reference System

The Global Positioning System

CORS and GIS

References

points that are a known distance apart. Triangulation formed the basis for many national surveys. By the end of the 19th century, major triangulation networks covered the United States, India, Great Britain, and large parts of Europe.



The concept of the shape of the Earth has changed dramatically over time as science and technology have continued to advance. ***Click on the image*** *for larger view.*

At the end of the 16th century, the Royal Society in London and the L'Academie Royale des Sciences in Paris were founded. Soon they became locked in a battle to determine the shape of the Earth. The French argued that the Earth was prolate, or shaped like an egg. The English, using Sir Isaac Newton's universal theory of gravity and the knowledge that the Earth spun around its axis, thought that the Earth was oblate, or flattened at the poles. To prove their idea, the Academy in Paris staged two expeditions, one to Peru (now Ecuador) at the equator, and the other to the border of Sweden and Finland in the northern hemisphere. Their objective was to measure the north-south curvature of the Earth at each location's latitude and determine whose concept of the Earth's shape was correct. The Academy's efforts proved that Newton was right. The Earth is flattened into the shape of an oblate sphere (Smith, 1988).

During the last 100 years, geodesy and its applications have advanced tremendously. The 20th century brought space-based technology, making geodetic measurements extremely precise. Today, NAVSTAR Global Positioning System satellites allow scientists to measure changes in the Earth's surface to the centimeter.

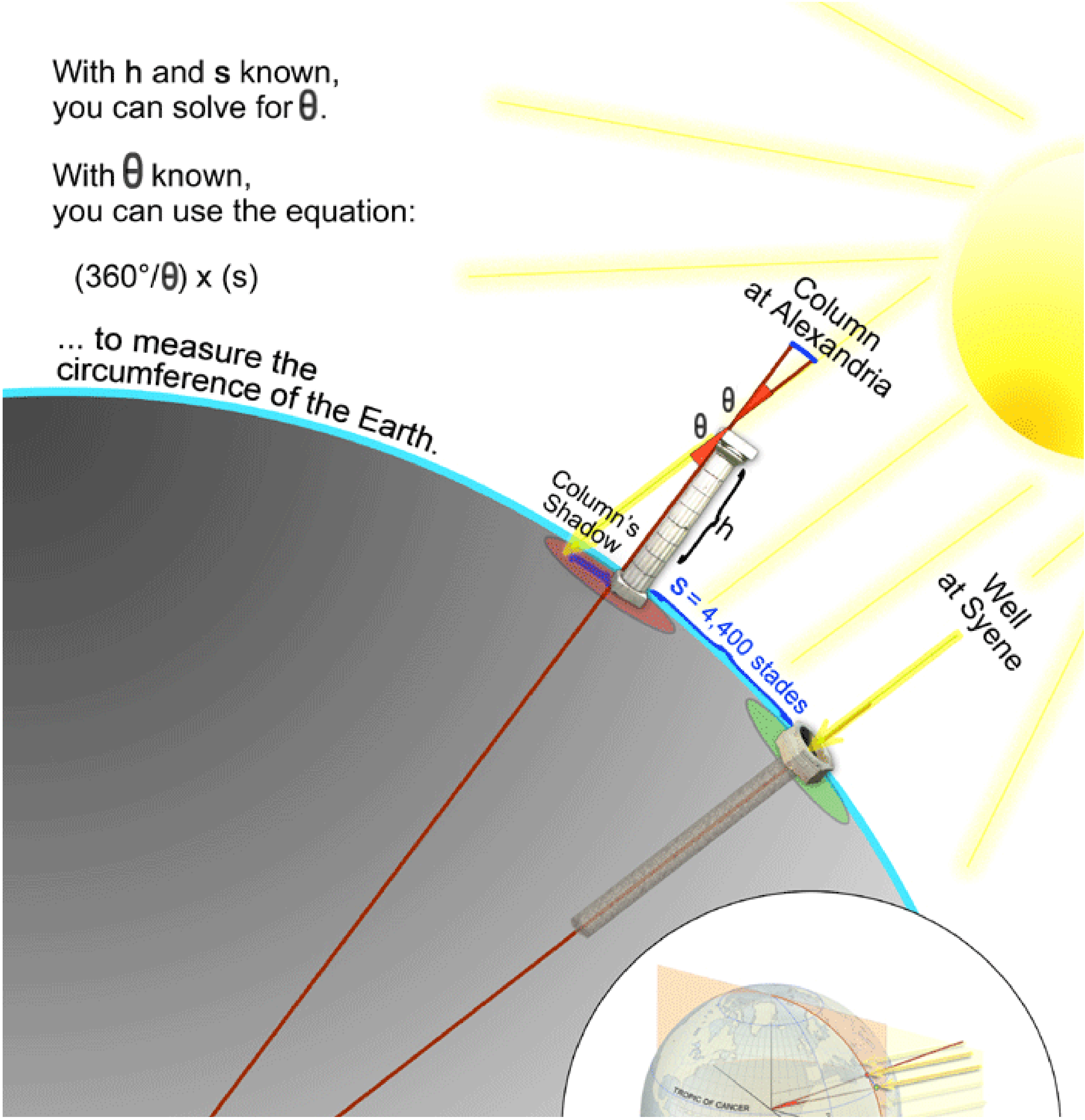
(top)
◀ ▶

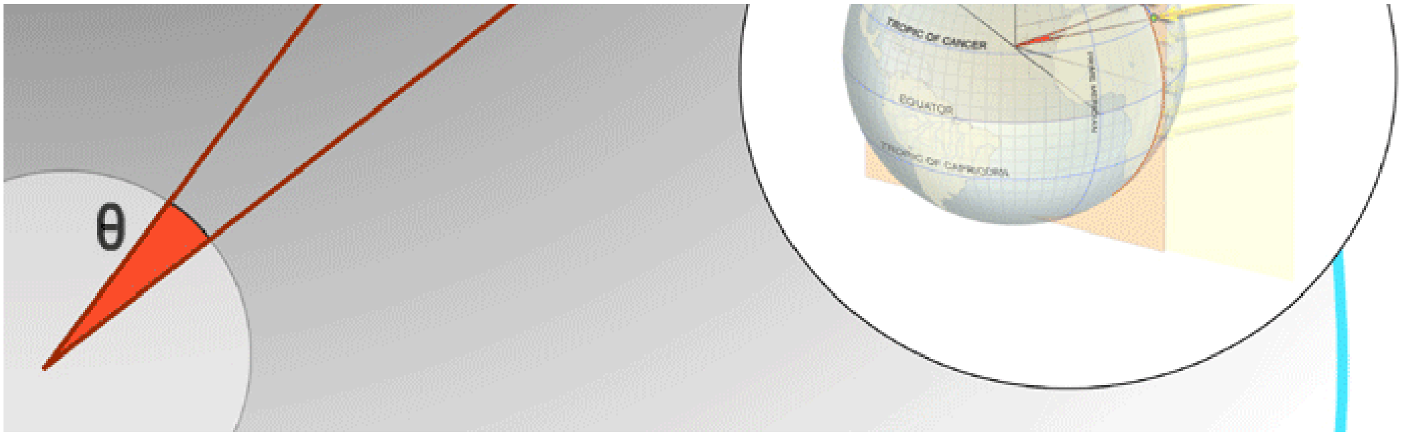
noaa ocean service education

Back

Return to **The History of Geodesy**

This illustration shows how Eratosthenes actually calculated the circumference of the Earth. At noon on the summer solstice, Eratosthenes measured the length of the shadow cast by a column of known height at Alexandria. With these two lengths, he could solve for the angle between them (θ). If the length of the shadow, and height of the column (h) were proportional to the distance between Alexandria and Syene (s=4,400 stades), and the radius of the Earth, then by calculating the angle on the column (θ), he was calculating the same angle formed at the center of the Earth (θ). The equation he used to determine the circumference of the Earth [(360° ÷ θ) x (s)] reflects this theory.

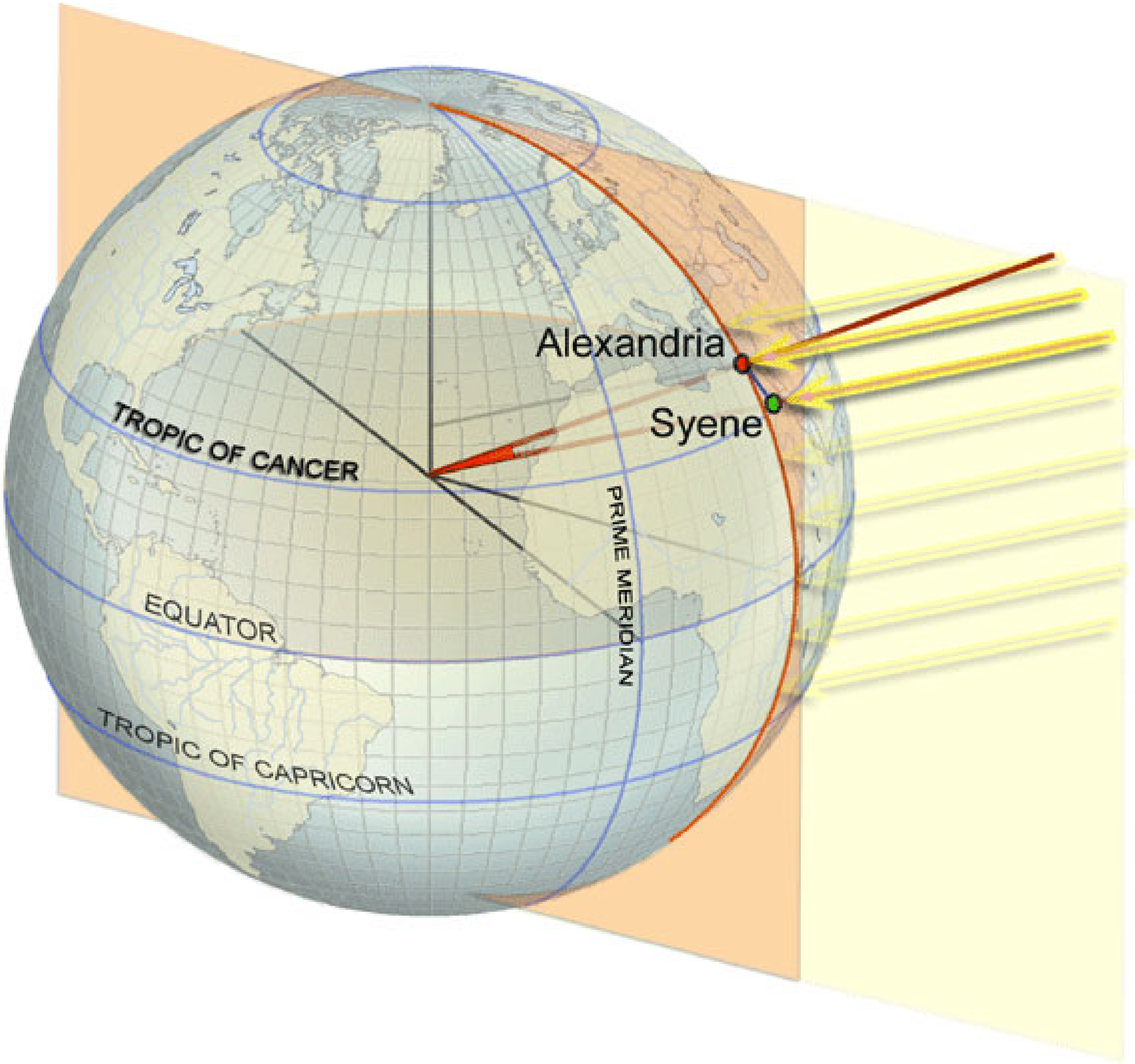



θ
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
PRIME MERIDIAN

(top)

Return to **The History of Geodesy**

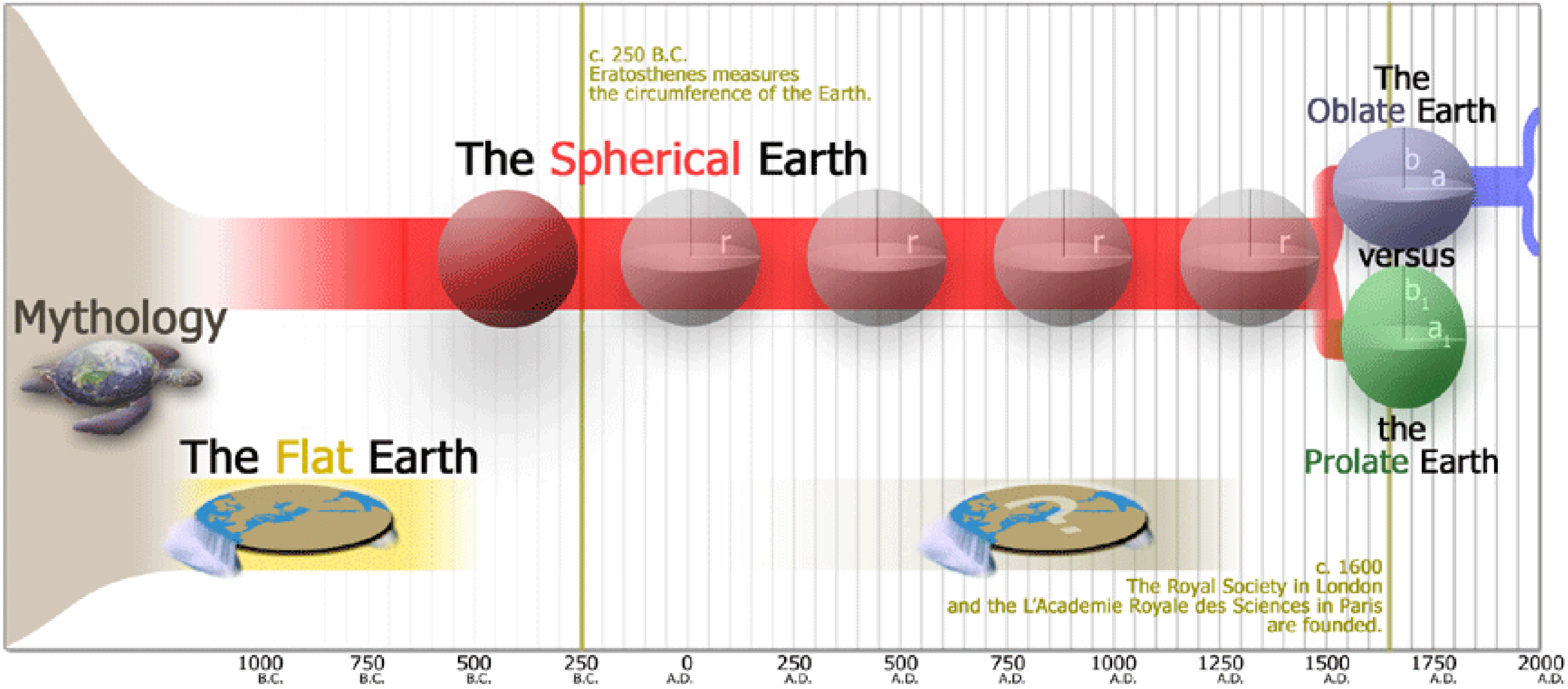
Eratosthenes' calculations were based on two assumptions. The first was that Syene lay on the Tropic of Cancer. The second assumption was that Alexandria lay due north of Syene on exactly the same line of longitude (the meridian line). At noon during the summer solstice, the rays of the sun always shine directly perpendicular to the Earth's surface, but only on the Tropic of Cancer. If Alexandria was exactly due north of Syene, then Eratosthenes could argue that the key measurements he used -- the length of the column's shadow in Alexandria and the distance between Alexandria and Syene -- were geographically sound.



(top)

Return to **The History of Geodesy**

Since the days of ancient mythology, scientists and philosophers have debated the shape of Earth. Since about 500 B.C., the idea that the Earth was a perfect sphere has dominated most scientific thinking, even though the concept of a flat Earth may have persisted in some regions for another millenium. Around the end of the 16th century, the idea that the Earth was a perfect sphere evolved into a radical new idea: that the Earth was an imperfect sphere. This new way of thinking was initially divided into two major schools of thought. One believed the Earth was egg-shaped (prolate). The other believed the Earth was flattened at the poles (oblate). The modern concept of a basically oblate Earth was demonstrated to be correct and has spawned many theoretical variations during the last hundred years as geodesy has advanced. **Use the slider bar** on the bottom of your browser to view the entire image.



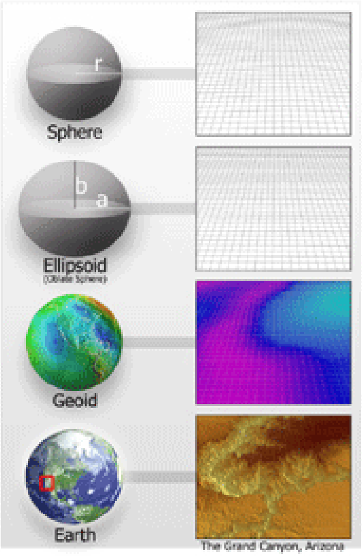
Geodesy

The Elements of Geodesy: The Figure of the Earth

◀ ▶

The Earth's shape is nearly spherical, with a radius of about 3,963 miles (6,378 km), and its surface is very irregular. Mountains and valleys make actually measuring this surface impossible because an infinite amount of data would be needed. For example, if you wanted to find the actual surface area of the Grand Canyon, you would have to cover every inch of land. It would take you many lifetimes to measure every crevice, valley, and rise. You could never complete the project because it would take too long.

To measure the Earth and avoid the problems that places like the Grand Canyon present, geodesists use a theoretical mathematical surface called the ellipsoid. Because the ellipsoid exists only in theory and not in real life, it can be completely smooth and does not take any irregularities - such as mountains or valleys -- into account. The ellipsoid is created by rotating an ellipse around its shorter axis. This matches the real Earth's shape, because the earth is slightly flattened at the poles and bulges at the equator.



Because the surface of the Earth is so complex, geodesists use simplified, mathematical models of the Earth for many applications. **Click on the image** for larger view.

While the ellipsoid gives a common reference to geodesists, it is still only a mathematical concept. Geodesists often need to account for the reality of the Earth's surface. To meet this need, the geoid, a shape that refers to global mean sea level, was created. If the geoid really existed, the surface of the Earth would be equal to a level in between the high-tide and low-tide marks.

Although a geoid may seem to be a smooth, regular shape, it isn't. The Earth's mass is unevenly distributed, meaning that certain areas of the planet experience more gravitational "pull" than others. Because of these variations in gravitational force, the "height" of different parts of the geoid is always changing, moving up and down in response to gravity. The geoidal surface is an irregular shape with a wavy appearance; there are rises in some areas and dips in others (Geodesy for the Layman, 1984).

(top)

◀ ▶

search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- **The Figure of the Earth**
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

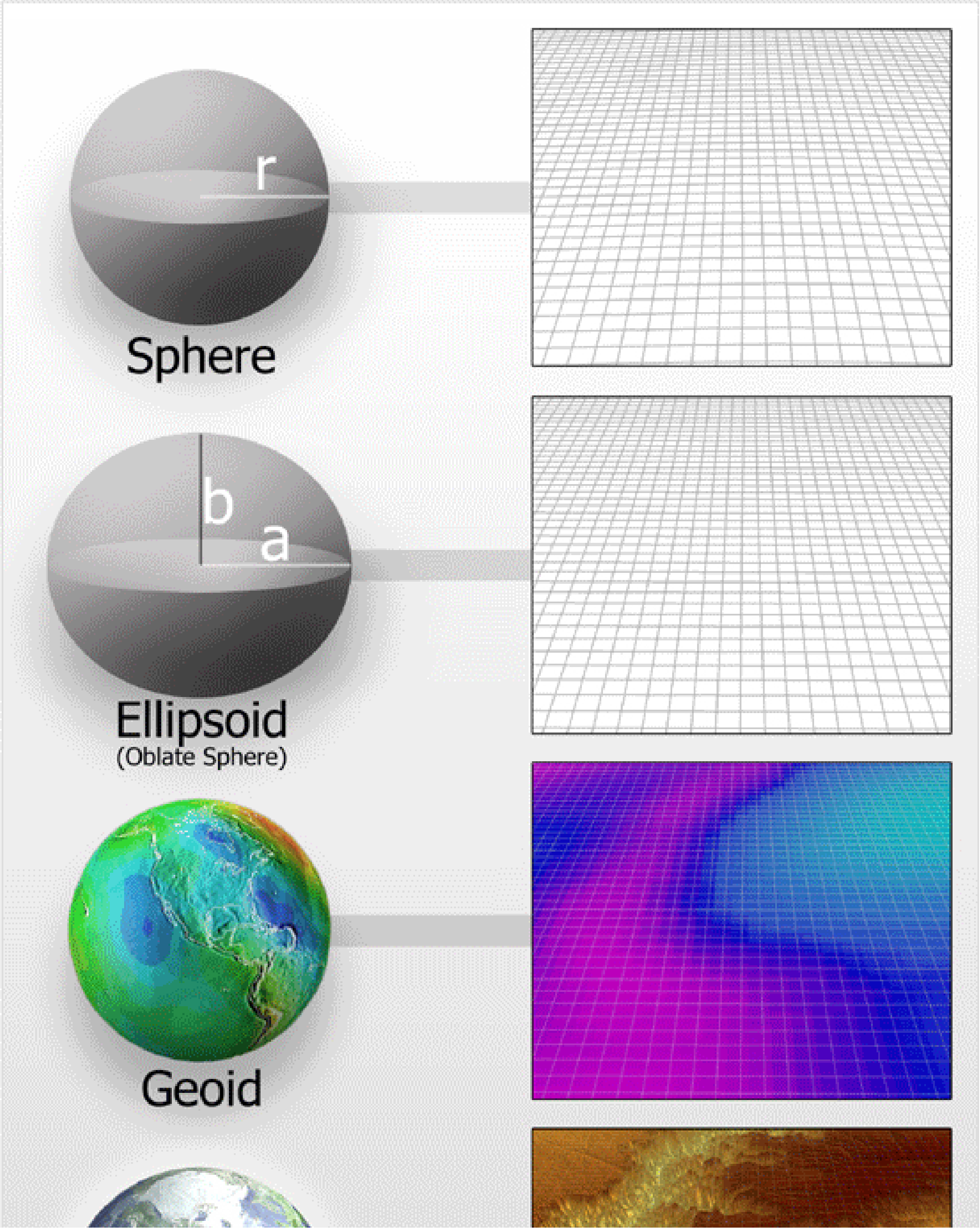
The Global Positioning System

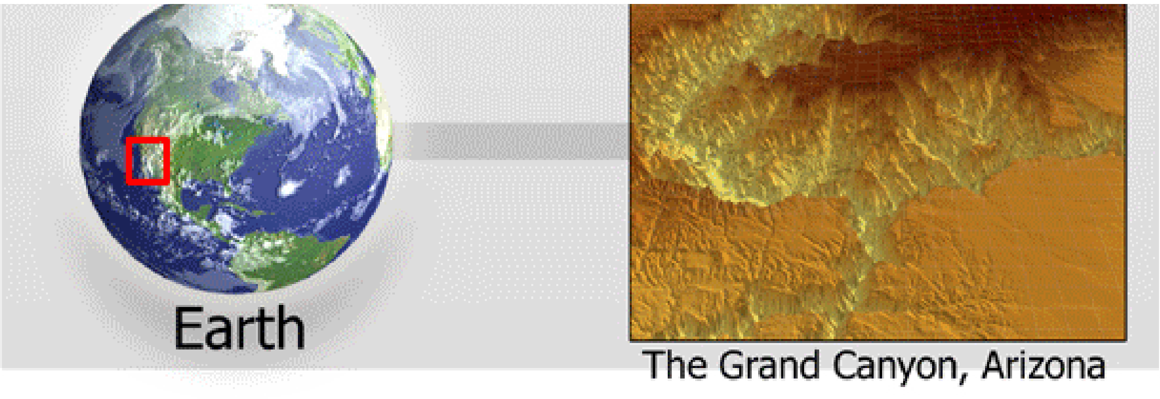
CORS and GIS

References

Return to **The Elements of Geodesy: The Figure of the Earth**

Because the surface of the Earth is irregular and complex, geodesists use simplified mathematical models of the Earth for many applications. The simplest model of the Earth is a sphere. A much more complex model of the Earth is the geoid, used to approximate mean sea level. Even the geoid is a simplified model, however, when compared to actual topographic relief, as shown in this image of four figures of the Earth (Grand Canyon).



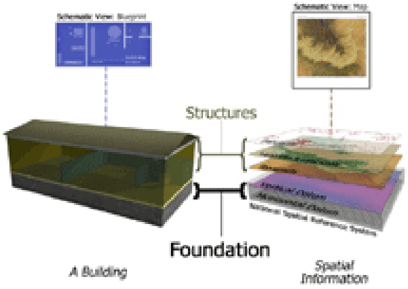


(top)

Geodesy

The Elements of Geodesy: Datums

Datums (sets of data) are the basis for all geodetic survey work. They act as reference points in the same way that starting points do when you give someone directions. For instance, when you want to tell someone how to get to your house, you give them a starting point that they know, like a road or a building. Geodesists and surveyors use datums as starting or reference points when they create maps, mark off property boundaries, and plan, design and build roads, bridges, and other structures.



One way to think about a datum is as a set of spatial information that acts as a foundation for other data, just like concrete acts as a foundation for a building. ***Click the image*** *for an animated view and large images.*

Another way to think about a datum is as a set of information that acts as a foundation for other data. For example, when a skyscraper is about to be built, the construction team must first pour the foundation. Without this element, the skyscraper would be unstable and unsafe. This is the same concept as a datum. While a datum is a mathematical and geometric concept, it acts like the concrete foundation of a skyscraper. Once the foundation is set, the construction workers can build on top of it, creating the building's structure. After the building is complete, offices or apartments can be created inside the building. If the structure is an apartment building, its tenants can bring in furniture and decorate as they please. Although the foundation of the building probably isn't the first thing on the minds of the tenants, without it, the building would not be a safe place to live.

In geodesy, two main datums create the foundation for navigation and transportation in the United States. These datums -- called the horizontal and vertical datums -- make up the National Spatial Reference System (NSRS). Geodesists, surveyors, and people interested in precise positioning use the NSRS as their foundation for reference.

(top)

○ This site ○ NOAA search

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- **Datums**
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

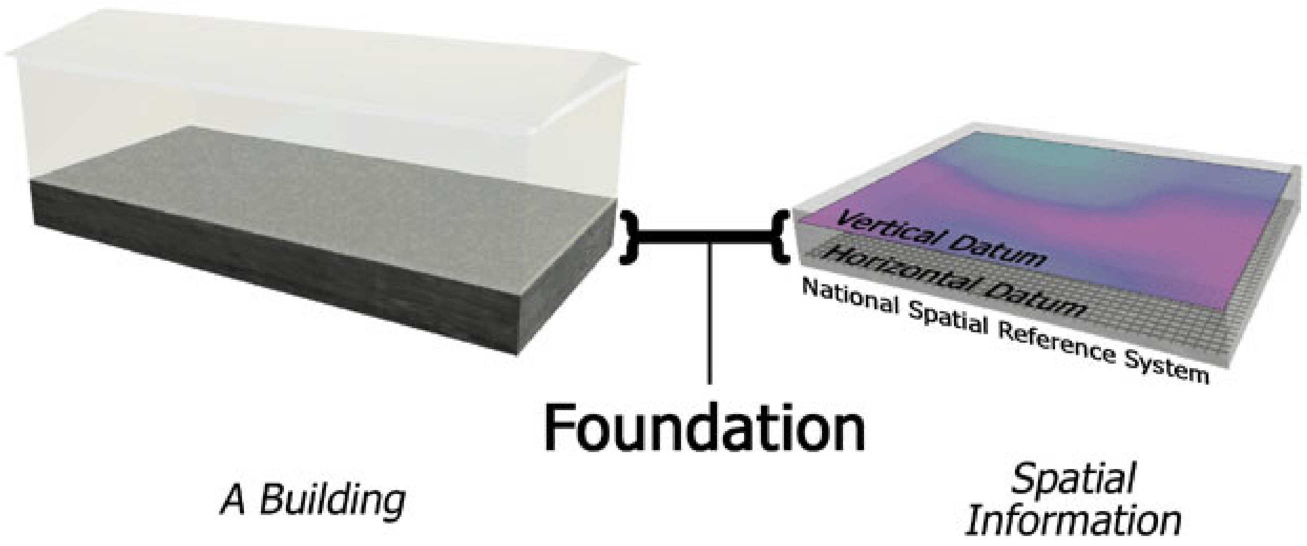
The Global Positioning System

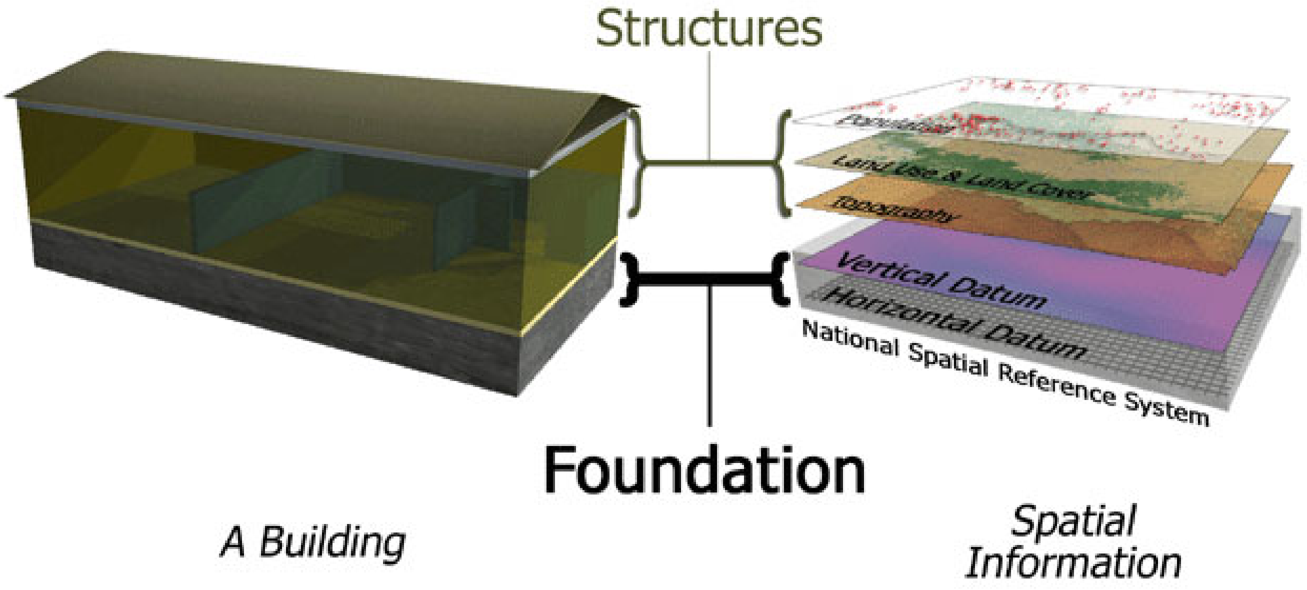
CORS and GIS

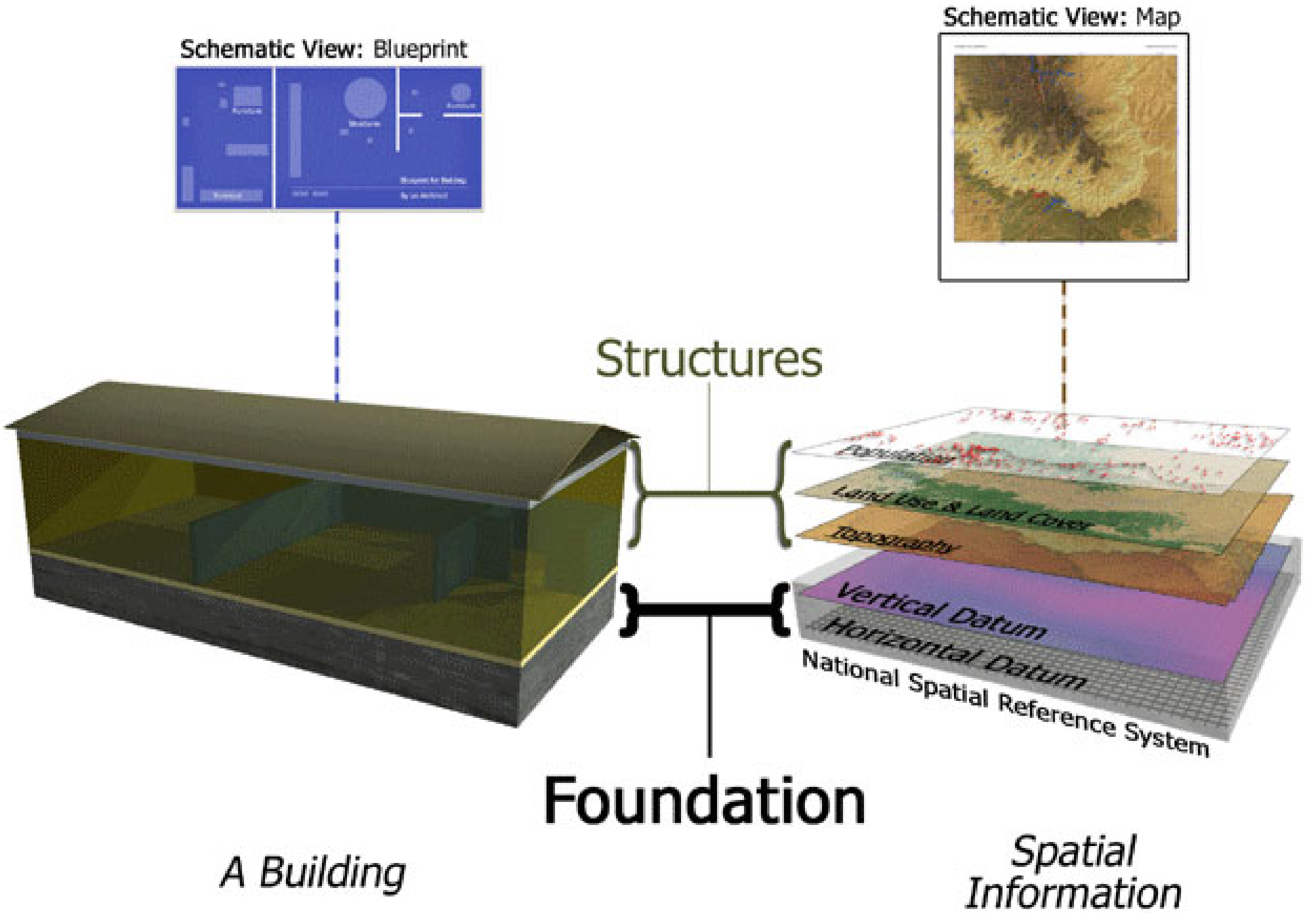
References

Return to **The Elements of Geodesy: Datums**

One way to think about a datum is as a set of spatial information that acts as a foundation for other data, just like concrete acts as a foundation for the structure of a building, including all the furnishings and decorations inside.Without a datum there would be nothing to securely support other spatial information, such as digital elevations, land use, or population. There are two types of datums, horizontal and vertical, that make up the National Spatial Reference System (NSRS). **Scroll down this page** to see a representation of how geodesists help others construct spatial information into a map, like designing or decorating the interior of a building, by providing a solid foundation. **Animated version**.






Schematic View: Blueprint
Schematic View: Map
Structures
Population
Land Use & Land Cover
Topography
Vertical Datum
Horizontal Datum
National Spatial Reference System
Foundation
A Building
Spatial Information

(top)

Geodesy

The Elements of Geodesy: The Horizontal Datum

◀ ▶

At its most basic level of definition, the horizontal datum is a collection of specific points on the Earth that have been identified according to their precise northerly or southerly location (latitude) and easterly or westerly location (longitude) (National Geodetic Survey, 1986).

Brass monuments permanently affixed in concrete or surrounding bedrock indicate accurate geodetic reference positions within the National Geodetic Survey's horizontal and/ or vertical datums. ***Click on the image*** *for larger view.*

To create the horizontal datum, or network of horizontal positions, surveyors marked each of the positions they had identified, typically with a brass, bronze, or aluminum disk or monument. These markers were placed so that surveyors could see one marked position from another. To maximize the line-of-sight between monuments, they were usually set on mountaintops or at high elevations. When monuments were set on flat land, towers were built above them to aid surveyors in locating them.

To "connect" the horizontal monuments into a unified network, or datum, surveyors have used a variety of methods, including triangulation. As technology has improved, surveyors now rely almost exclusively on the Global Positioning System (GPS) to identify locations on the Earth and incorporate them into existing datums.

In 1927 the U.S. Coast and Geodetic Survey, the predecessor of the National Geodetic Survey, "connected" all of the existing horizontal monuments together and created the North American Datum of 1927 (NAD 27). This datum was used extensively during the next 60 years as the primary reference for horizontal positioning. In 1983, NAD 27 was adjusted to remove inaccuracies and to correct distortions. The new datum, called NAD 83, is the most commonly used horizontal positioning datum today in the United States.

One application of the horizontal datum is monitoring the movement of the Earth's crust. This type of monitoring is often used in places like the San Andreas Fault in California where many earthquakes occur. Extending from northern California south to San Bernardino, the San Andreas Fault is where two plates of the Earth's crust meet. The fault is approximately 800 miles long and extends 10 miles below the Earth's surface. By looking at the movement of monuments in the horizontal datum, geodesists can determine just how much the surface of the Earth has moved after an earthquake (Schultz and Wallace, 1997).

☐ search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- **The Horizontal Datum**
- The Vertical Datum
- Gravity

The National Spatial Reference System

The Global Positioning System

CORS and GIS

References

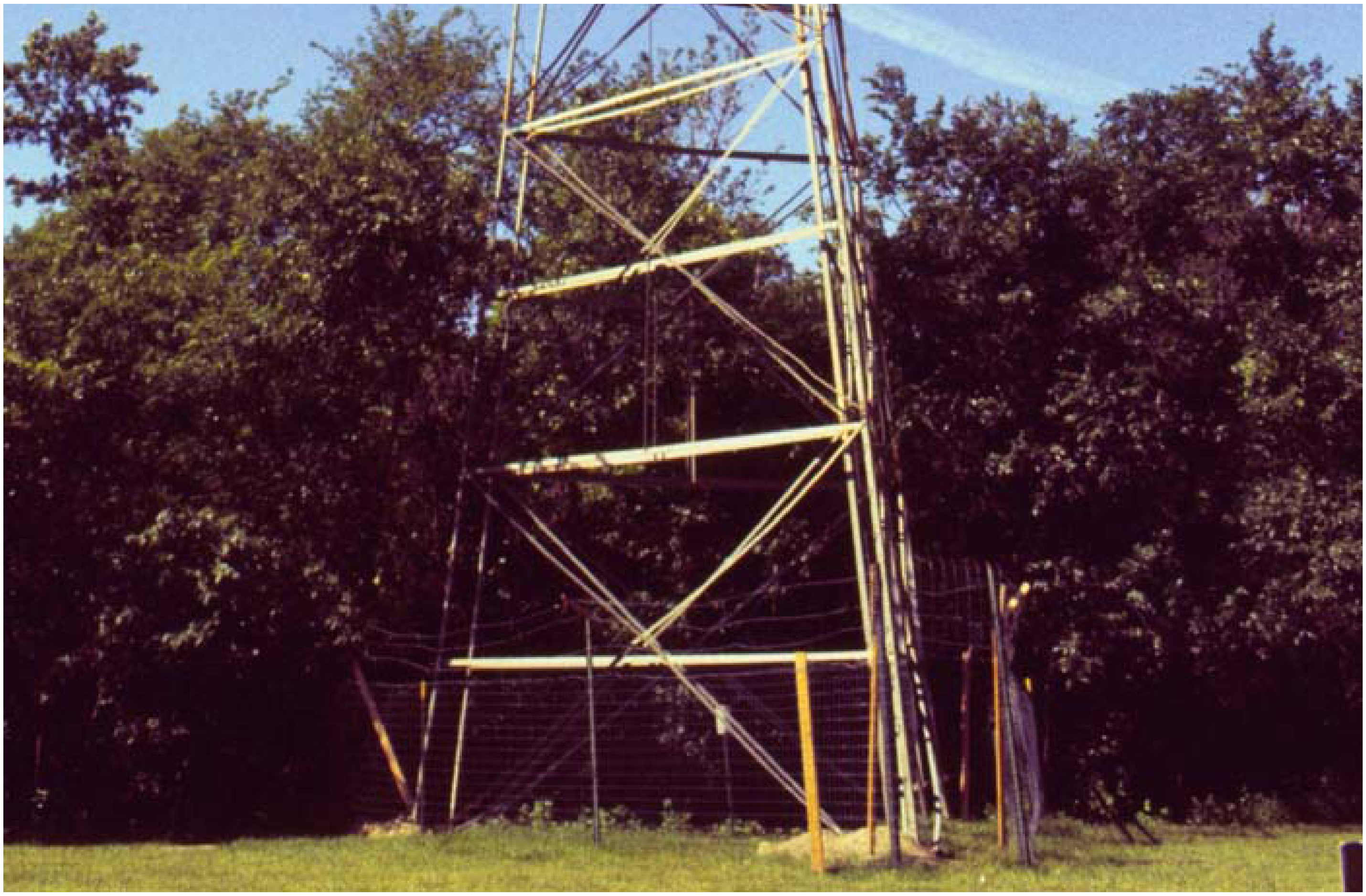
Return to **The Elements of Geodesy: The Horizontal Datum**

Brass monuments permanently affixed in concrete or surrounding bedrock indicate accurate geodetic reference positions within the National Geodetic Survey's horizontal and/or vertical datums.

(top)

Return to **The Elements of Geodesy: The Horizontal Datum**

Before the Global Positioning System became available for use by the general public, geodesists would "connect" geodetic reference points together using a method called triangulation. This method required a "line of sight" between monuments. When the monument was located on flat ground, large towers such as this were often erected above them. This allowed geodesists to observe the monuments' accurate position over large distances.



(top)

Geodesy

The Elements of Geodesy: The Vertical Datum

The vertical datum is a collection of specific points on the Earth with known heights either above or below mean sea level. Near coastal areas, mean sea level is determined with a tide gauge. In areas far away from the shore, mean sea level is determined by the shape of the geoid.

Similar to the survey markers used to identify known positions in the horizontal datum, round brass plates mark positions in the vertical datum. The traditional method for setting these vertical benchmarks is called differential leveling. This method uses a known elevation at one location to determine the elevation at another location. As with horizontal datums, the advanced technology of GPS has almost completely replaced this classical technique of vertical measurement.

The position of this vertical survey marker in Louisiana has been upset due to significant subsidence (sinking) of the surrounding area. ***Click on the image*** *for a larger view.*

In 1929, the National Geodetic Survey (NGS) compiled all of the existing vertical benchmarks and created the National Geodetic Vertical Datum of 1929 (NGVD 29). Since then, movements of the Earth's crust have changed the elevations of many benchmarks. In 1988, NGVD 29 was adjusted to remove inaccuracies and to correct distortions. The new datum, called the North American Vertical Datum of 1988 (NAVD 88), is the most commonly used vertical datum in the United States today.

One of the main uses of the vertical datum is to measure rates of subsidence, or land sinking. In Louisiana, for example, large areas of land are rapidly sinking. This is the result of development, coastal erosion, and high population levels. In many areas, the only way to escape an incoming hurricane is to follow specific hurricane evacuation routes. If state and local officials do not have accurate elevation information about these routes, residents trying to leave during an emergency might get trapped in fast-rising water.

By referencing the vertical datum, officials can determine the true elevation and position of the hurricane evacuation routes, as well as how much they have sunk over past decades. For example, in Plaquemines Parish, Louisiana, the main hurricane evacuation route, Highway 23, and the surrounding levees are subsiding by one-quarter to one-half inch per year.

Highway 23 is the main hurricane evacuation route for the entire state of Louisiana. Vertical benchmarks used together with the Global Position System have been critical in tracking rates of subsidence in the area and allowing officials to develop emergency evacuation plans. ***Click on the image*** *for a larger view*.

(top)

search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- **The Vertical Datum**
- Gravity

The National Spatial Reference System

The Global Positioning System

CORS and GIS

References

◂ Back ◂

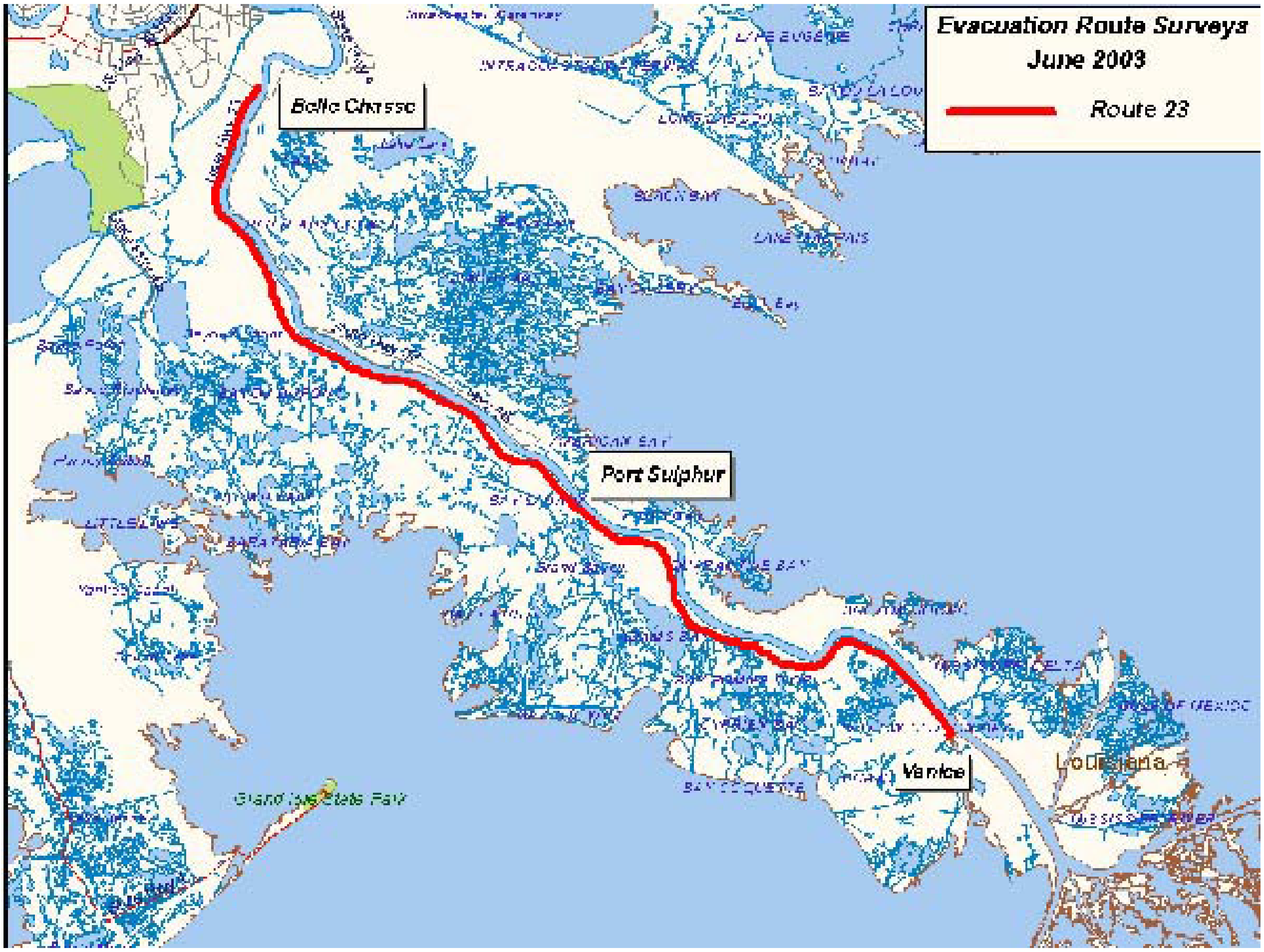
Return to **The Elements of Geodesy: The Vertical Datum**

Similar to the survey markers used to identify positions in the horizontal datum, round brass plates mark positions in the vertical datum. The markers are embedded in concrete or bedrock to maintain their positions and, therefore, the integrity of the geodetic control point. Here we see how the position of a vertical survey marker in Louisiana has been upset due to significant subsidence (sinking) of the surrounding area.

(top)

Return to **The Elements of Geodesy: The Vertical Datum**

Highway 23 is the main hurricane evacuation route for the entire state of Louisiana. Vertical benchmarks have been critical in tracking the rate of subsidence in the area and allowing officials to develop up to date emergency evacuation plans.



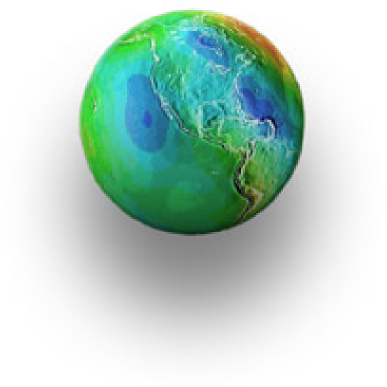
(top)

Geodesy

The Elements of Geodesy: Gravity

◀ ▶

Gravity is the force that pulls all objects in the universe toward each other. On Earth, gravity pulls all objects "downward" toward the center of the planet. According to Sir Isaac Newton's Universal Law of Gravitation, the gravitational attraction between two bodies is stronger when the masses of the objects are greater and closer together. This rule applies to the Earth's gravitational field as well. Because the Earth rotates and its mass and density vary at different locations on the planet, gravity also varies.



Imagine if all the mountains and valleys were scoured off the planet leaving a continuous world ocean completely at rest. The effects of the Earth's gravity on this hypothetical world mean sea level is represented by the geoid. ***Click on the image*** *for a larger view and more images.*

One reason that geodesists measure variations in the Earth's gravity is because gravity plays a major role in determining mean sea level. Geodesists calculate the elevation of locations on the Earth's surface based on the mean sea level. So knowing how gravity changes sea level helps geodesists make more accurate measurements. In general, in areas of the planet where gravitational forces are stronger, the mean sea level will be higher. In areas where the Earth's gravitational forces are weaker, the mean sea level will be lower.

To measure the Earth's gravity field, geodesists use instruments in space and on land. In space, satellites gather data on gravitational changes as they pass over points on the Earth's surface. On land, devices called gravimeters measure the Earth's gravitational pull on a suspended mass. With this data, geodesists can create detailed maps of gravitational fields and adjust elevations on existing maps. Gravity principally affects the vertical datum because it changes the elevation of the land surface (Geodesy for the Layman, 1984).

(top)

◀ ▶

search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- **Gravity**

The National Spatial Reference System

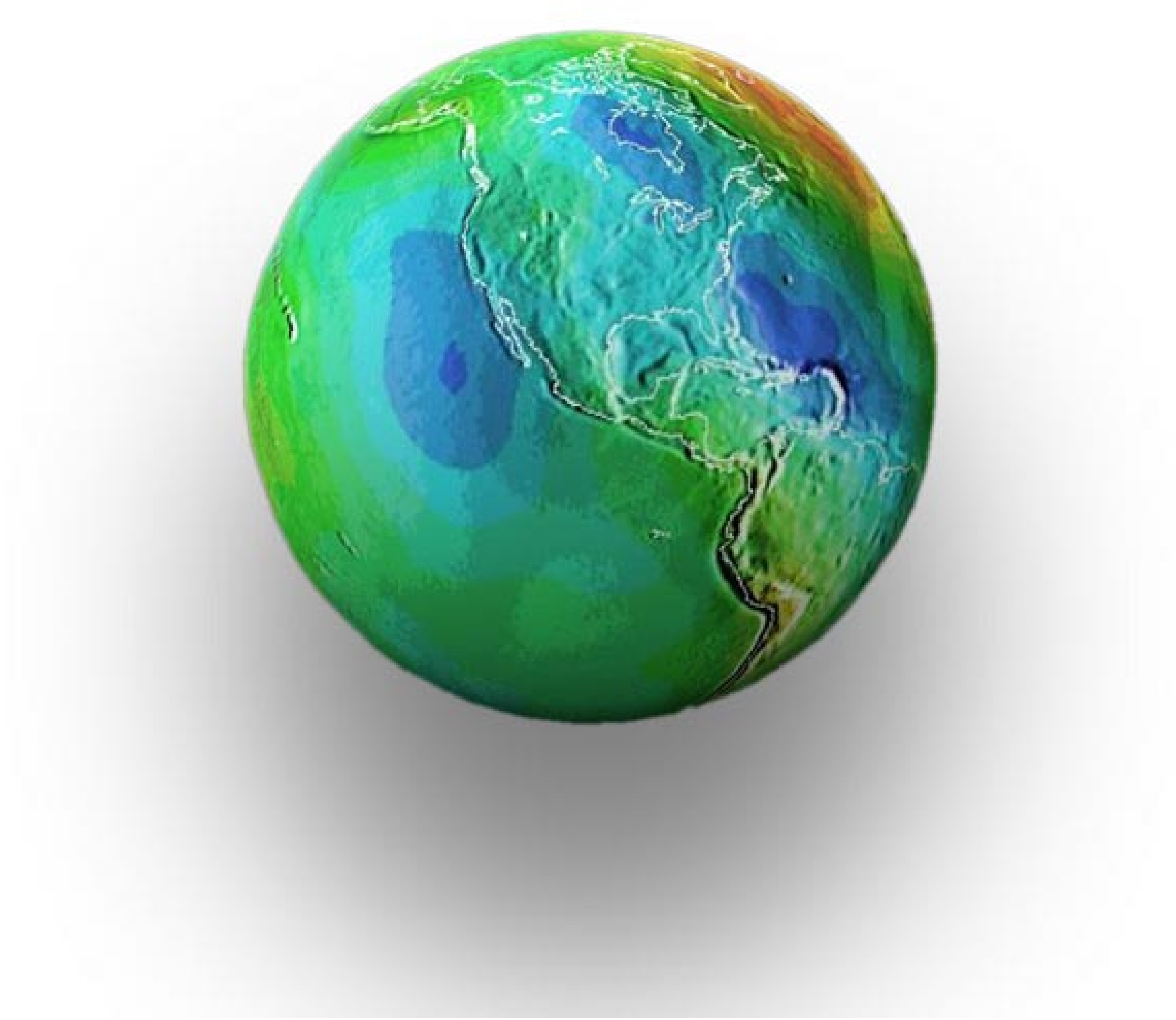
The Global Positioning System

CORS and GIS

References

Return to **The Elements of Geodesy: Gravity**

Imagine if all of the Earth topography, mountains and valleys were scoured off leaving a continuous world's ocean completely at rest, without the effects of currents, weather and tides. The effect of the Earth's gravity on this hypothetical world mean sea level is represented by the geoid. However, because the Earth's gravity is not equal in all places, this hypothetical ocean is not perfectly smooth. The strength of the Earths' gravity, and consequent effect on the shape of the geoid is represented by color variations in this image. **Click on the image** to see another example.



(top)

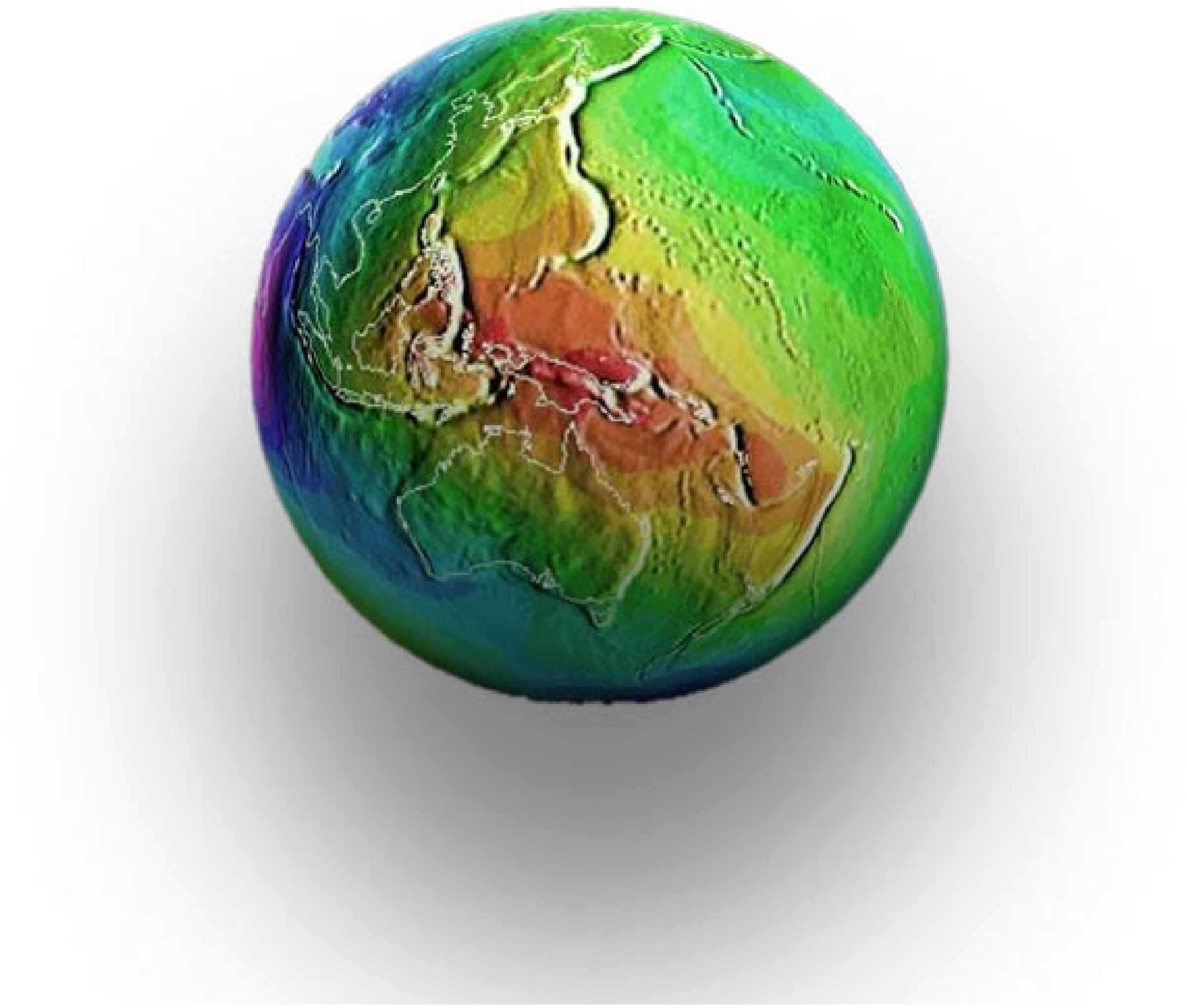
Return to **The Elements of Geodesy: Gravity**

In this global map of the geoid (Geoid99), the area in blue near India indicates a region where the Earth's gravity is weaker. In this area, the mean sea level is lower because the hypothetical ocean has been pulled away from the area of lower gravitational force towards other areas of the globe where the gravitational forces are stronger. **Click on the image** to see another example.

(top)

Return to **The Elements of Geodesy: Gravity**

In this global map of the geoid (Geoid99), the area in red in the South Pacific just north of Australia indicates a region where the Earth's gravitational pull is stronger. Here, the mean sea level is higher because the hypothetical ocean has been pulled towards this area where gravity is stronger. In fact, if you stood at sea level in the area near India (where the Earth's gravity is weaker) you would be a little bit lighter than if you stood at sea level just north of Australia in the South Pacific where the Earth's gravitational force is stronger.



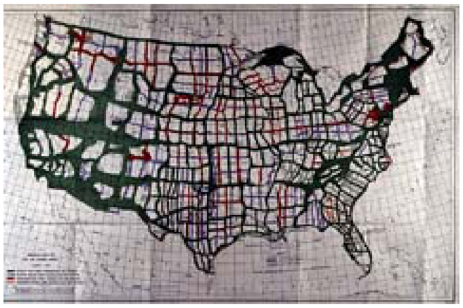
(top)

Geodesy

The National Spatial Reference System

◀ ▶

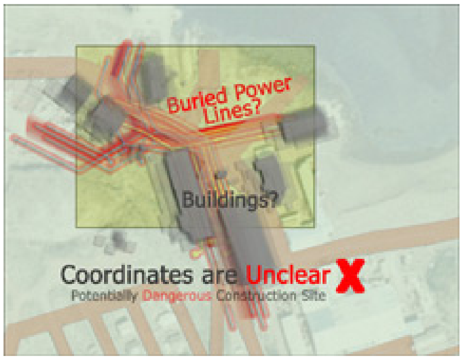
All of the elements of geodesy are joined together in the National Spatial Reference System (NSRS). For almost 200 years, the National Geodetic Survey (NGS) and its predecessors have been using geodesy to map the U.S. shoreline, determine land boundaries, and improve transportation and navigation safety. NGS evolved from the Survey of the Coast, an agency established by Thomas Jefferson in 1807. The creation of the United States' first civilian scientific agency was prompted by the increasing importance of waterborne commerce to the fledgling country. As the nation grew westward, NGS's mission began to include surveys of the North American interior.



A United States triangulation network map from 1937. This system was a precursor to today's modern National Spatial Reference System. ***Click on the image*** *for larger view.*

With numerous surveys being conducted simultaneously across the growing nation, the surveyors needed to establish a common set of reference points. This would insure that surveyors' maps and charts, which often covered hundreds of miles, would align with each other and not overlap. The common set of reference points they used were the benchmarks from the horizontal and vertical datums. Today, the complete set of vertical and horizontal benchmarks for the United States is known as the NSRS. This defined group of reference points acts as the foundation for innumerable activities requiring accurate geodetic information.

Think of it this way: When construction workers begin to build, they have to be sure that the area where they are building is free from dangerous power lines. The construction team will have to find out where the power lines are and make sure they are not building on top of them. To ensure success, the team needs to know the coordinates of the building site and of the local power lines. The NSRS provides a framework for identifying these coordinates. The team can then compare the two sets of coordinates and make sure they do not overlap.



The National Spatial Reference System (NSRS) is as the foundation for many activities requiring accurate spatial information. ***Click on the image*** *to see an animated example of how the NSRS works.*

To identify the benchmarks in the NSRS, NGS has traditionally placed markers, or permanent monuments, where the coordinates have been determined. These markers are brass or bronze disks (metals that sustain weathering) and are set in concrete or bedrock. Each marker is about 9 centimeters wide and has information about NGS printed on its surface.

With the advent of the Global Positioning System (GPS), NGS began to use different kinds of markers. These are made from long steel rods, driven to refusal (pushed into the ground until they won't go any farther.) The top of each rod is then covered with a metal plate. This method ensures that the mark won't move and that people can't destroy or remove it. After tying these marks into a specific horizontal or vertical datum, the mark can be included in the NSRS database. Once the coordinates of the mark are entered into this database, they are available for anyone to use.

search
○ This site ○ NOASA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

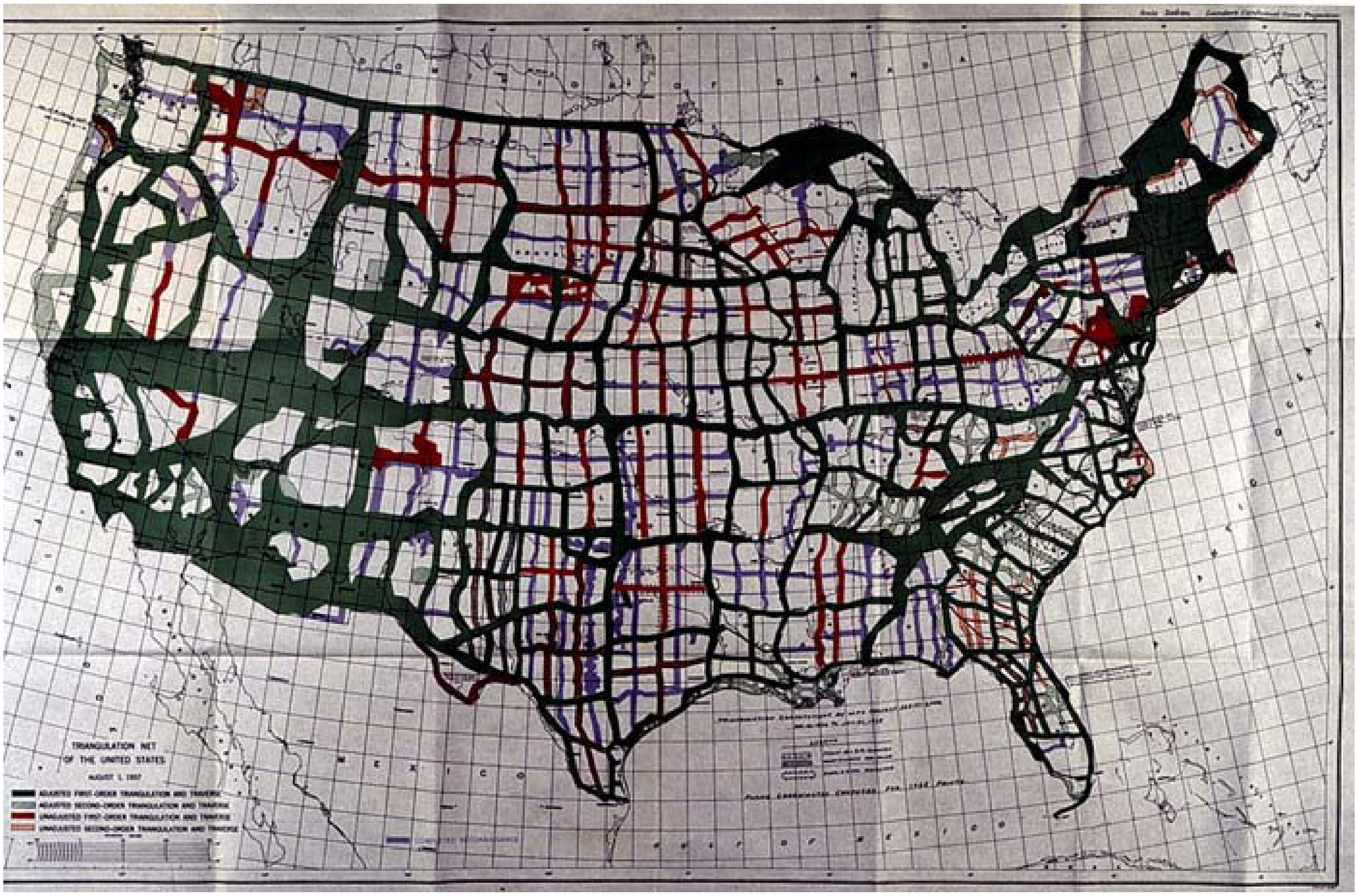
The Global Positioning System

CORS and GIS

References

Return to **The National Spatial Reference System**

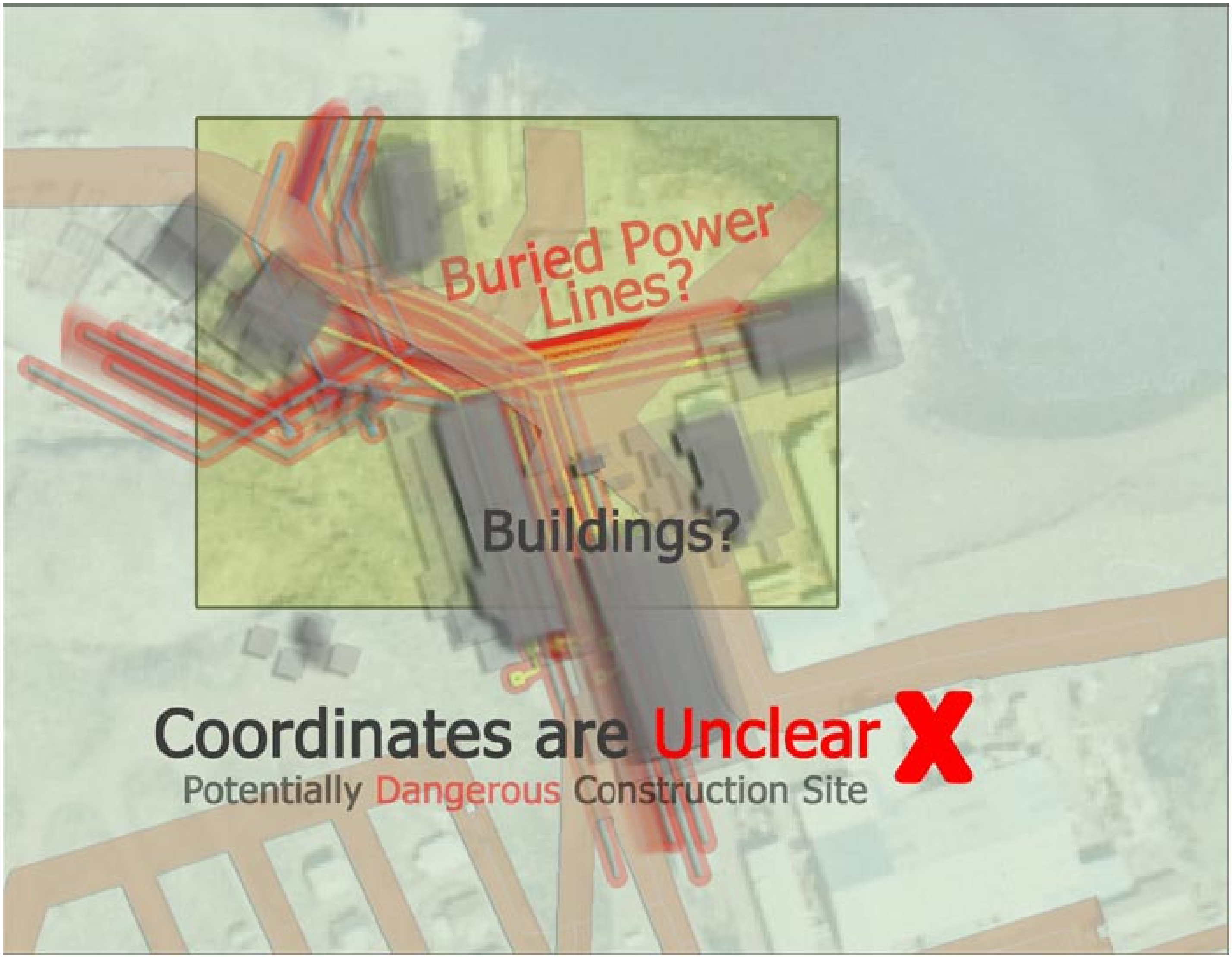
A United States triangulation network map from 1937. Developing a network of areas based on manual surveys using triangulation was a precursor to today's modern National Spatial Reference System, which is overseen and continuously monitored by the Global Positioning System.

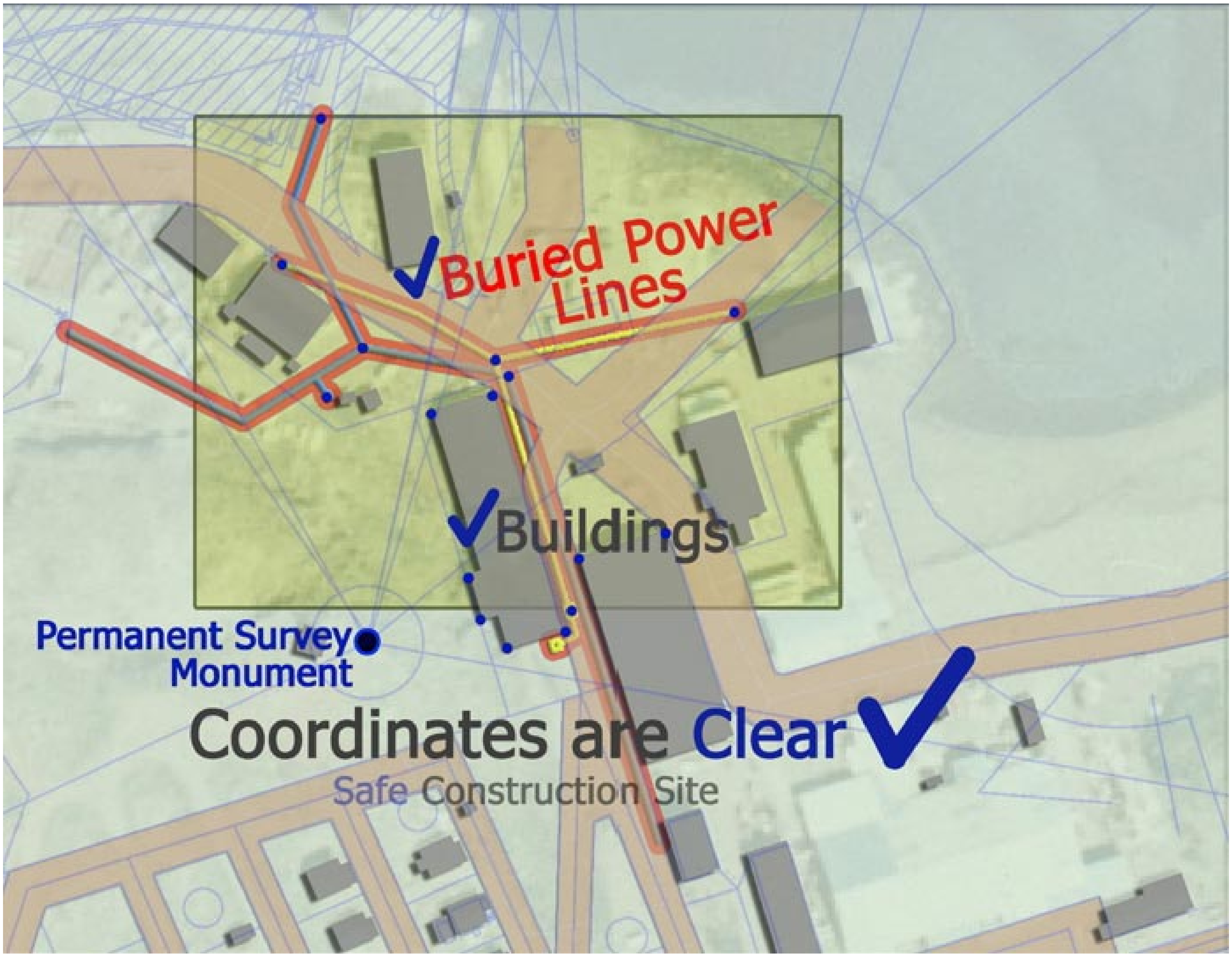


(top)

Return to **The National Spatial Reference System**

The National Spatial Reference System (NSRS) is a set of permanent monuments that act as the foundation for many activities requiring accurate spatial information. For example, when construction workers are working near a building, they need to know where the building lies in relation to power lines. Without the NSRS, the location of the buildings and the power line are unclear. View the imags below to see the difference the NSRS can make. By comparing the coordinates for the location of the building and the power lines, the construction team will have a clear picture of where things lie and can avoid potentially dangerous situations. **Animated version**.




✓Buried Power Lines
✓Buildings
Permanent Survey Monument
Coordinates are Clear ✓
Safe Construction Site

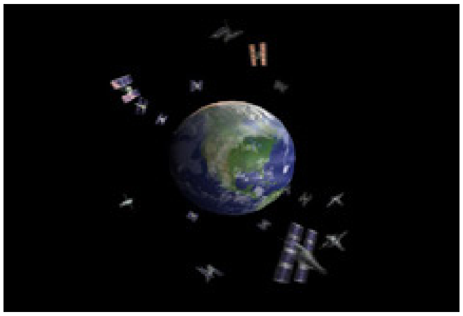
(top)

Geodesy

Do you know where you are? - The Global Positioning System

◀ ▶

Using the Global Positioning System (GPS), every point on Earth can be given its own unique address -- its latitude, longitude, and height. The U.S. Department of Defense developed GPS satellites as a strategic system in 1978. But now, anyone can gather data from them. For instance, many new cars have a GPS receiver built into them. These receivers help drivers know exactly where they are, and can help them from getting lost.



The Global Positioning System (GPS) is a constellation of satellites orbiting the Earth approximately 11,000 miles in space. ***Click on the image*** *for an animated view.*

GPS is a constellation of satellites that orbit approximately 11,000 miles above the Earth and transmit radio wave signals to receivers across the planet. By determining the time that it takes for a GPS satellite signal to reach your receiver, you can calculate your distance to the satellite and figure out your exact location on the Earth. Sound easy? In fact it is a very complicated process. For the GPS system to work, you need to have incredibly precise clocks on the satellites and receivers, and you must be able to access and interpret the signals from several orbiting satellites simultaneously. Fortunately, the receivers take care of all the calculations.

Let's tackle the distance calculation first. GPS satellites have very precise clocks that tell time to within 40 nanoseconds or 40 billionths (0.000000040) of a second. There are also clocks in the GPS receivers. Radio wave signals from the satellites travel at 186,000 miles per second. To find the distance from a satellite to a receiver, use the following equation: (186,000 mi/sec) x (signal travel time in seconds) = Distance of the satellite to the receiver in miles.

Knowing the distance of your GPS receiver to a single satellite is useful, but it will not provide you with enough information to determine your exact position on the Earth. For that, you need to simultaneously access the signals from four satellites. By calculating its distance from three satellites simultaneously, a GPS receiver can determine its general position with respect to latitude, longitude, and elevation.

It takes four GPS satellites to calculate a precise location on the Earth using the Global Positioning System. ***Click on the image*** *for larger view.*

You may wonder why the GPS receiver needs a fourth satellite. Essentially, it provides for even greater precision. To accurately calculate the distance from the GPS receiver to each of the three orbiting satellites, you must know the precise radio signal transmission and reception times. To do this, the clocks in the satellites and the clocks in the receivers must be perfectly synchronized. A mismatch of as little as one millionth of a second between the clock in the satellite and the clock in the receiver could translate into a positioning error of as much as 900 feet (Herring). The atomic clocks in the satellites are extremely accurate, but the clocks in the GPS receivers are not, which

☐ search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

The Global Positioning System

CORS and GIS

References

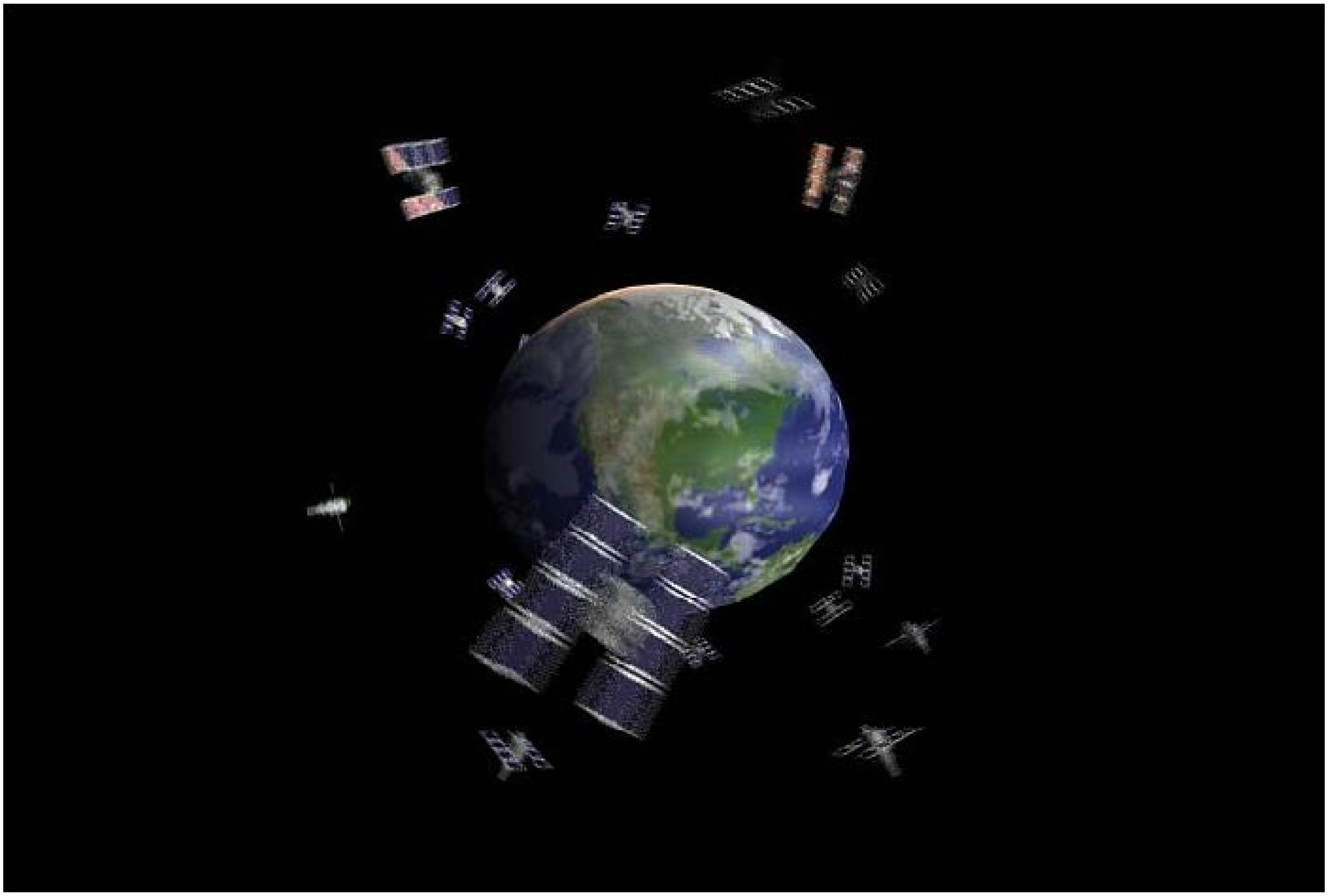
creates a timing error. The signal from the fourth satellite is used to adjust for the receiver clock error and calculate the receiver's correct position. So, the receiver needs at least four satellite signals to calculate a position. But if the receiver can access more satellite signals, it will calculate a more accurate position (Tinambunan).

(top)

◀ ▶

Return to **The Global Positioning System**

The Global Positioning System (GPS) is a constellation of satellites orbiting the Earth approximately 11,000 miles in space. The GPS satellites in this animation are not drawn to scale. However, their orbits and orientation to the Earth are approximately correct. GPS satellites are organized into six different orbital paths completely covering the Earth. Looking at the Earth top down from the North Pole, the six orbits are spaced at 60 degree intervals. Looking at the Earth from the equator, each orbit is moderately tilted at 50 degrees. **Animated version**.

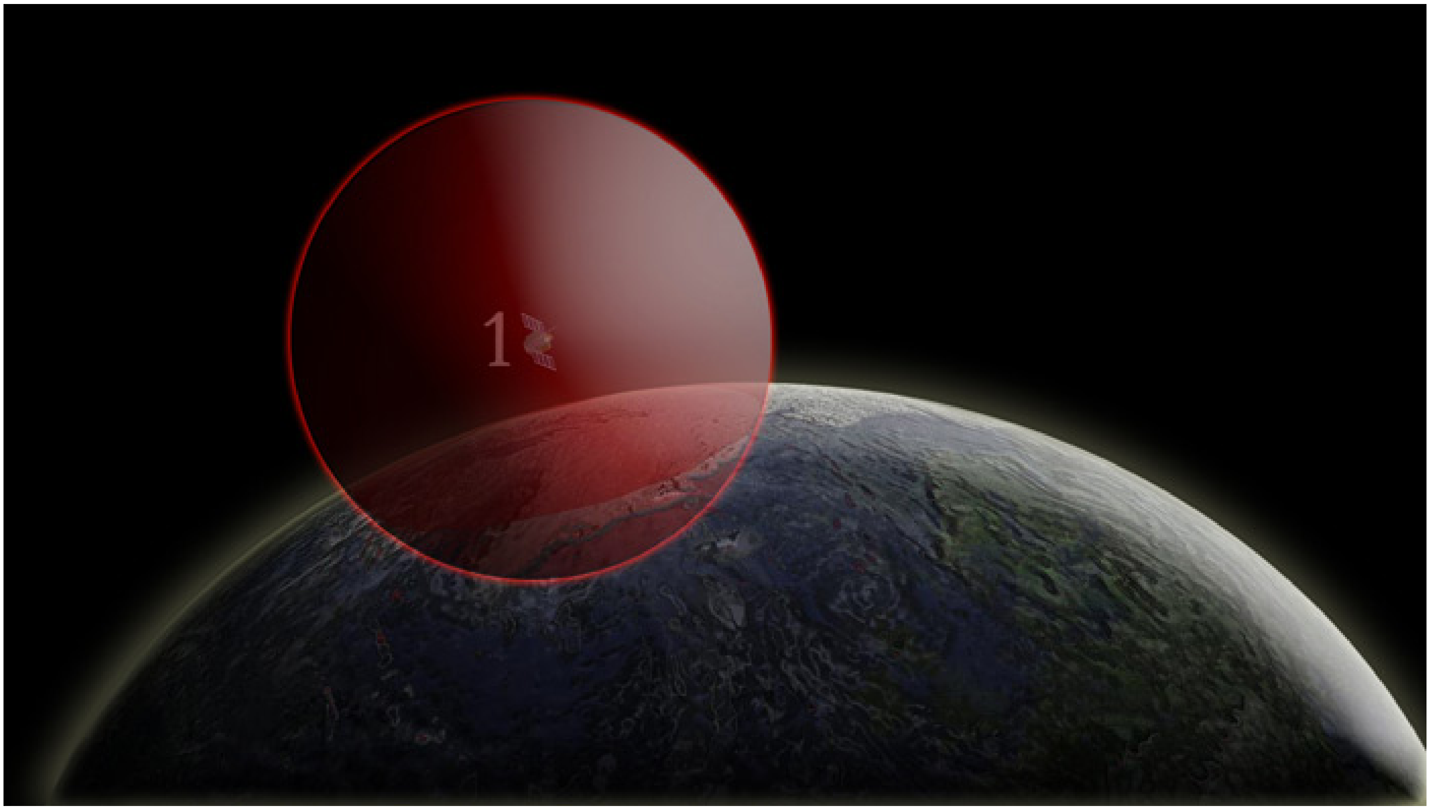


(top)

Return to **The Global Positioning System**

It takes four GPS satellites to calculate a precise location on the Earth using the Global Positioning System: three to determine a position on the Earth, and one to adjust for the error in the receiver's clock. If you were 15,000 miles from only one satellite (satellite with red sphere), you could be anywhere on an imaginary red sphere that has a radius equal to the number of miles from the satellite (15,000 miles). **Click on the arrow below** to see what happens when you add another satellite.

Click the arrow to add another satellite ▶

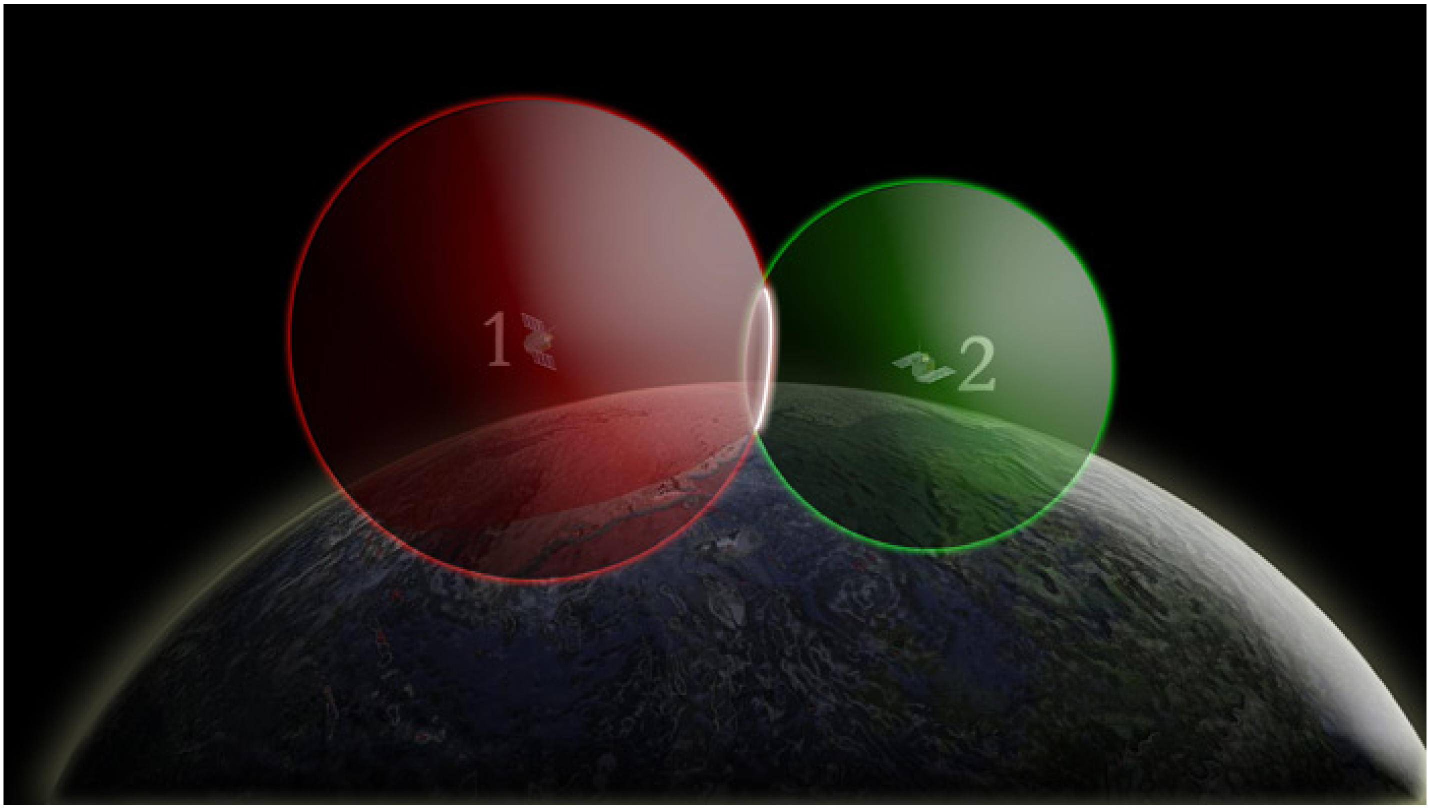


(top)

Return to **The Global Positioning System**

When you add a second satellite (satellite with green sphere), about 12,000 miles away, you can only be where these two imaginary spheres intersect (the white circle). **Click on the arrow below** to see what happens when you add another satellite.

Click the arrow to add another satellite ▶

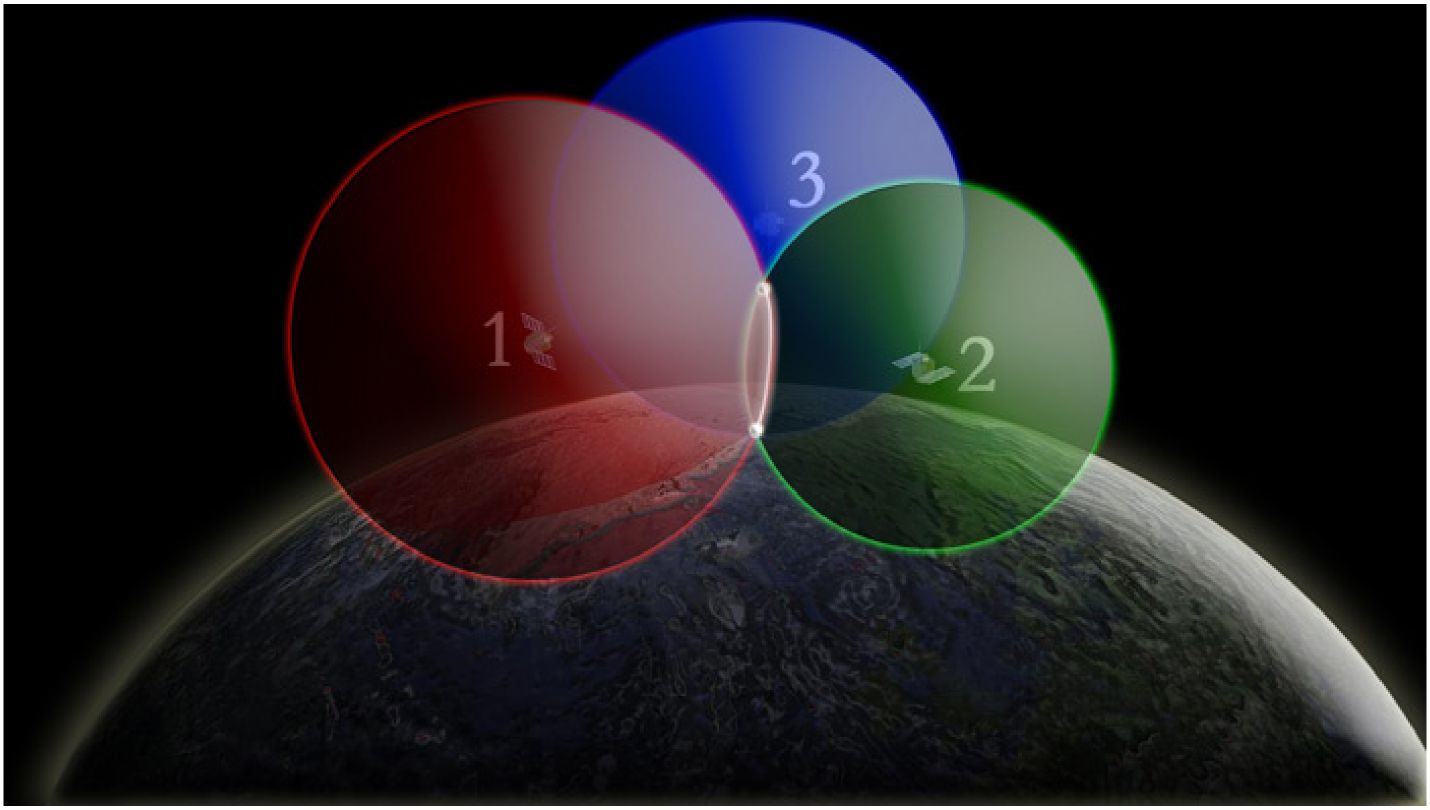


(top)

Return to **The Global Positioning System**

When you add a third satellite (satellite with a blue sphere) you can come close to finding your exact position on the Earth. Imagine that you are 14,000 miles from the third satellite. In this situation, there are only two points (the two white points) where you could possibly be. These points are where the 14,000-mile sphere intersects with the 15,000-mile and 12,000-mile spheres. **Click on the arrow below** to see what happens when you add another satellite.

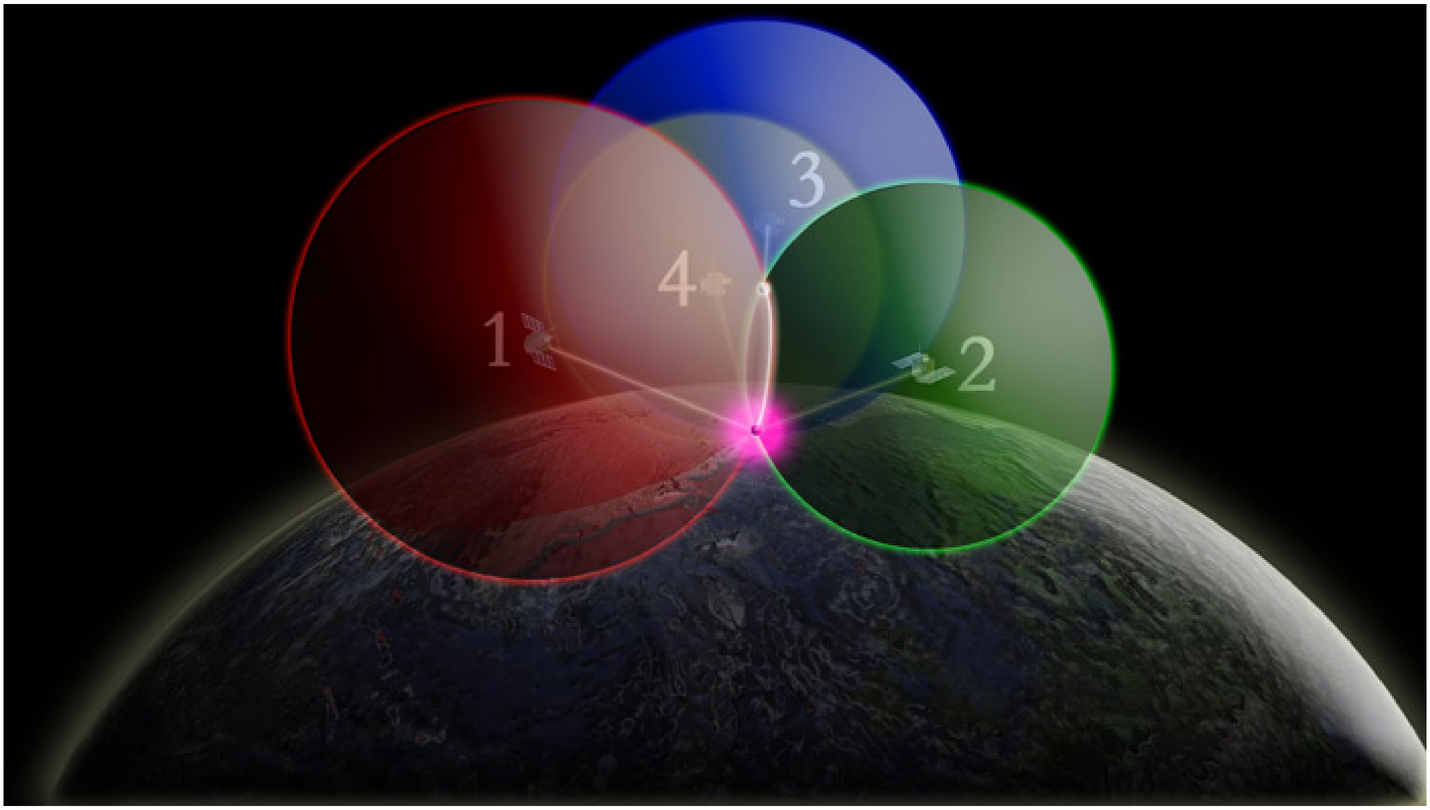
Click the arrow to add another satellite ▶



(top)

Return to **The Global Positioning System**

To correct for the GPS receiver's clock error and find your precise position, a fourth satellite (satellite with the yellow sphere) must be used. With the fourth satellite, small timing errors from all four satellites to the point on the Earth have been adjusted, and your exact location on the Earth (the purple point) can be determined.



(top)

Geodesy

Taking it to the next level: CORS and GIS

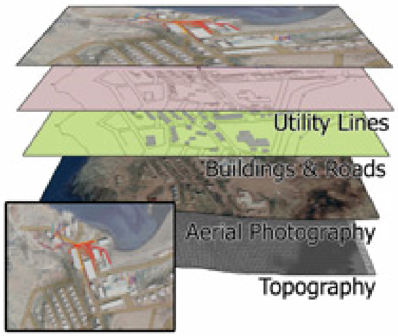
◀ ▶

The Continuously Operating Reference Stations (CORS) system is a network that continually corrects GPS signals, and provides these corrections to GPS users over the Internet. ***Click on the image*** *for larger view.*

In a field of study that is thousands of years old, GPS represents a quantum leap in geodesy. As advanced as GPS technology is, most commercially available GPS receivers are only accurate within several meters. Considering that the Earth is almost 25,000 miles in circumference, the difference of a few meters may not seem important. This level of accuracy may be adequate for a hiker in the woods or someone driving a car. But there are many scientific, military, and engineering activities that require much higher levels of positioning accuracy - often to within a few centimeters or less!

To provide measurements at this level of accuracy, NGS developed the Continuously Operating Reference Stations (CORS) network. CORS is a network of hundreds of stationary, permanently operating GPS receivers throughout the United States. Working 24 hours a day, seven days a week, CORS stations continuously receive GPS radio signals and integrate their positional data into the National Spatial Reference System. This data is then distributed over the Internet. After logging onto the CORS Web site, users can determine the accuracy of their coordinates to the centimeter. This system has been especially useful in assessing the integrity of buildings and bridges in areas that are geologically active or have been impacted by natural disasters such as hurricanes or floods.

Another powerful tool that has evolved along with GPS technology is the Geographic Information System (GIS). A GIS is comprised of three parts: spatial information, special software, and a computer. These components work together to provide a digital platform for viewing and processing layers of spatial information.



Information about a place in a GIS is stored in several separate but overlapping layers that represent utility lines, buildings, roads, aerial photography, and topography. ***Click on the image*** *for larger view and animation.*

A GIS assembles information from a several of sources, including ground surveys, existing maps, aerial photos, and satellite imagery. In a GIS, specific information about a place, such as the locations of utility lines, roads, streams, buildings, and even trees and animal populations, is layered over a set of geodetic data. Using special software, regional planners and scientists can examine the layers individually or in various combinations to improve traffic flow, merge construction with utility systems, develop around environmentally sensitive areas, and protect the public from potential natural disasters. Because a GIS stores data digitally, information can be quickly and economically updated, easily reproduced, and made widely available. In fact, because of its power and speed, GIS technology is doing most of the cartographic (mapmaking) work that, in the past, was laboriously done by hand on paper charts and maps.

☐ search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:

- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

The Global Positioning System

CORS and GIS

References

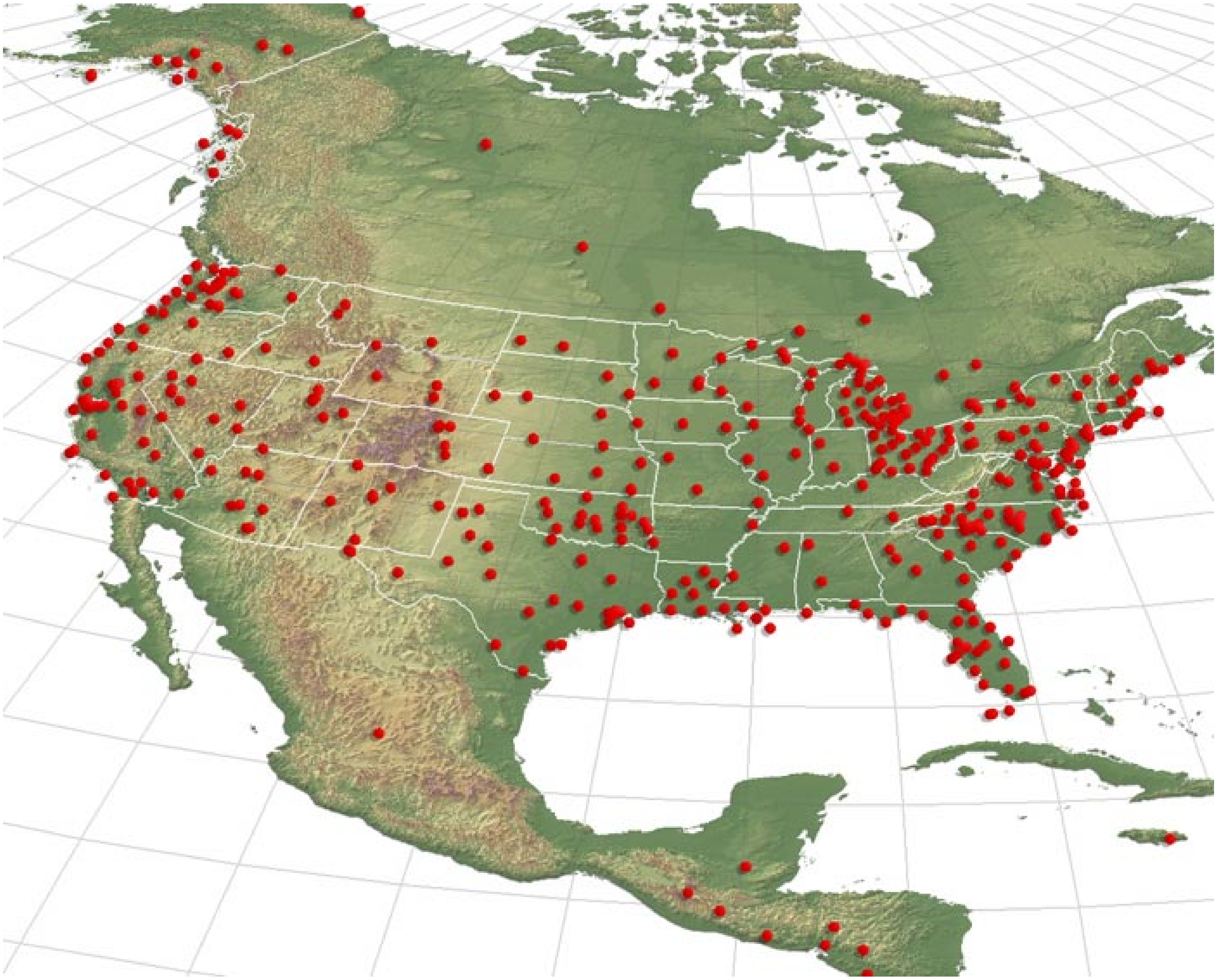
The most important element needed to reconstruct geographic reality in a GIS is good spatial information. If the spatial information provided to a GIS is sparse or of poor resolution, then the world created by the computer will be a lifeless digital shell -- a sharp contrast to the complexity of our living Earth.

(top)

◀ ▶

Return to **Taking it to the next level: CORS and GIS**

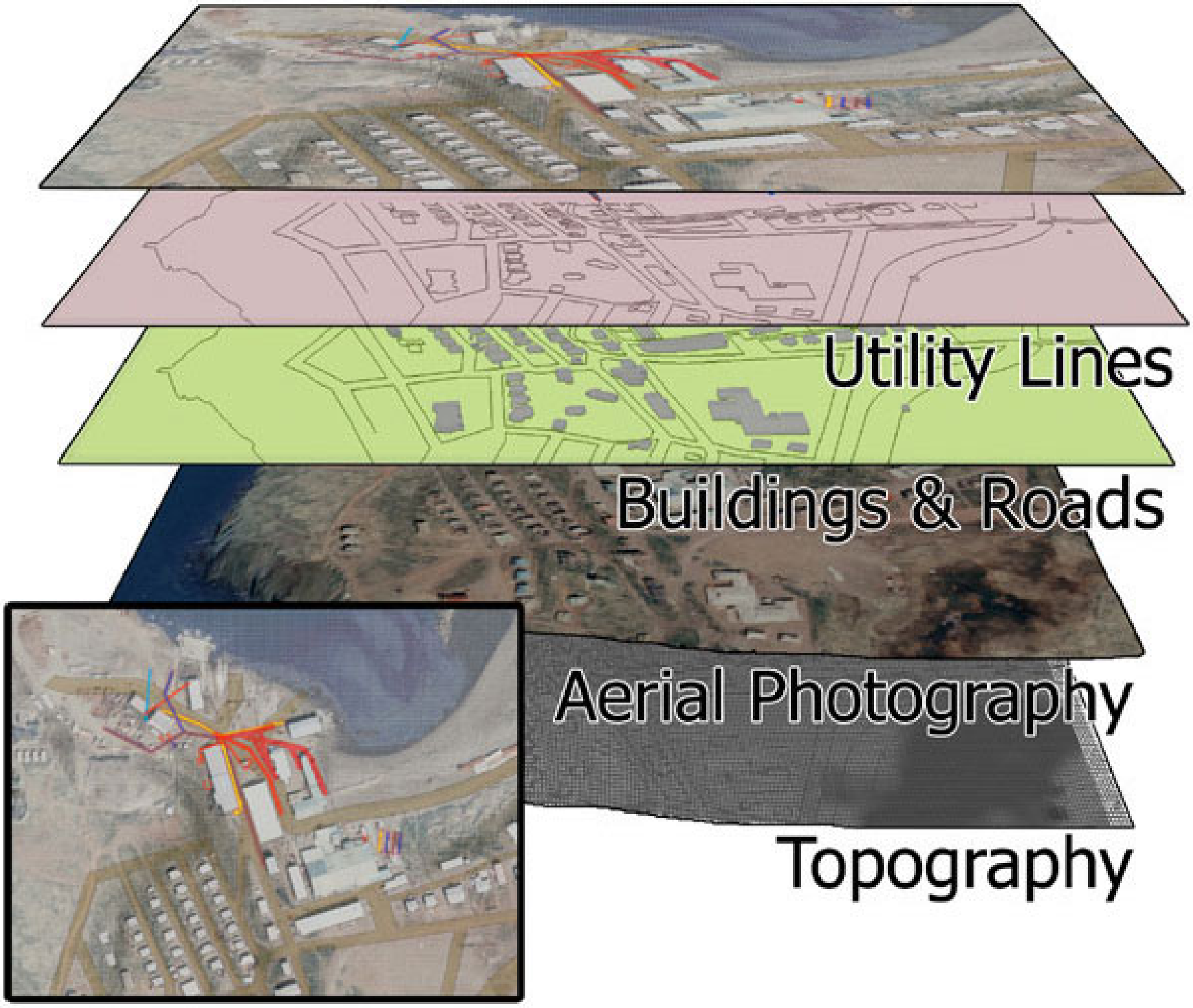
The Continuously Operating Reference Stations (CORS) system is a network of stations throughout the United States and its territories that continually record GPS signals, and then provide the data to GPS users over the Internet.



(top)

Return to **Taking it to the next level: CORS and GIS**

Information about a place in a GIS is stored in several separate but overlapping layers that represent utility lines, buildings, roads, aerial photography, and topography. **Click on the image to view an animation** of how these layers all fit together.



(top)

Geodesy

References

◀ ▶

Careers in Geodesy. 1986. The American Geophysical Union Section of Geodesy. Washington, DC: American Geophysical Union. 30 pp.

Geodesy for the Layman. 1984. Washington, DC: Defense Mapping Agency. Online at: http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003A.HTM.

Geodetic Glossary. 1986. Rockville, MD. National Geodetic Survey. 266 pp.

Herring, Thomas. 1996, February. The Global Positioning System. Scientific American, 44-50.

Hurn, Jeff. 1989. GPS: A Guide to the Next Utility. Sunnyvale, CA: Trimble Navigation Ltd. 76 pp.

Schultz, Sandra S. and Robert E. Wallace. 1997. The San Andreas Fault. United States Geological Survey. Online at: http://pubs.usgs.gov/gip/earthq3/safaultgip.html.

Smith, J.R. 1988. Basic Geodesy. Rancho Cordova, CA: Landmark Enterprises. 135 pp.

Tinambunan, D. 2003. How do GPS devices work? ScientificAmerican.com. Online at: http://www.sciam.com/askexpert_question.cfm? articleID=000349D4-D6FC-1CFC-93F6809EC5880000&catID=3.

Vanicek, Petr. 2000. An Online Tutorial in Geodesy. Academic Press. Online at: http://einstein.gge.unb.ca/tutorial/tutorial.htm.

(top)

◀ ▶

search
○ This site ○ NOAA

Geodesy Roadmap

Geodesy Lesson Plans

Welcome

What is Geodesy

The History of Geodesy

The Elements of Geodesy:
- The Figure of the Earth
- Datums
- The Horizontal Datum
- The Vertical Datum
- Gravity

The National Spatial Reference System

The Global Positioning System

CORS and GIS

References