

Background on The Geographic Coordinate System and Map Projections

Outline

- 1. Introduction**
- 2. Datums and the Geographic Coordinate System**
- 3. Map projections**

1. Introduction

Much of this basic map coordinates material in these notes may be well-known to many students in this class. I address this topic because so much visualization is related to the Earth. The applications of GIS (there are two meanings: Geographic Information Science and Geographic Information Systems) are expanding rapidly. They touch our lives in more and more ways, from tools like MapQuest that help us get from one location to another, to studies of global warming that is affecting our climate now and should be affecting our planning for the future.

In putting the material together for Sections 2 and 3 in this set of class notes, I want to avoid materials presented in class (with attribution) from copyrighted sources. This included material from an ESRI publication and from one of Mark Monmonier's books called *Mapping it Out*. (I recommend his books and he has several.) Rather than rewrite a lot, I have included material from the web with only little modification. I want to thank the people that contribute to wikipedia and those in the federal agencies who endeavor to make their scientific knowledge and resources available to the public.

In my web exploration I encountered two links that I want to share in case some of you might be interested. Visualization related to invasive species could make a very good class project.

[USGS Biological Science Programs](#)

[Defense Technical Information Center Search](#)

Section 4 turns toward new methodology. As our increasingly powerful data collection, computing and visualization tools help us step up to the challenges of larger area geospatial analysis and to global analysis, there is opportunity to develop new methodology and reconsider current methodology that has been part of our scientific working infrastructure.

In Section 4, I call attention to the continuing efforts of Tony Olsen (US EPA) and several collaborators to develop and deploy geospatial sampling methodology. The methodology has been used by various states and nations. Earlier this month (March 2007), Tony and collaborators released the spsurvey (Spatial Survey Design and

Analysis) R package to make tools widely available. Over a decade of research is behind these tools. (Perhaps a student project would develop a class exercise for future years that illustrate good uses of this tool set.)

I once heard mention of sampling to determine which satellite images to obtain for a resource assessment analysis. The reality is that costs limit the amount data we can gather for analysis, whether the data comes from ground samples, satellite images, or other sources. Perhaps one or more students in this class will find a use for the sampling methodology.

Section 4 also contains a little about the facet of Tony's research that addressed the selection of the global grids to use in sampling. Coherent sampling frames facilitate combining data over space and time. Kevin Sahr was a key player in this research. I was involved in the periphery.

As a side note, Tony provided graphics challenges for me to address in various contexts. His direct question to me about linking row-labeled plots to maps triggered my almost instant solution that we now called linked micromap plots or micromaps for short.

2. Datums and the Geographic Coordinate System

Map coordinates and elevations are developed from frames of reference. The basic frames of reference for coordinates are called datums.

Datum: (DOD, NATO) Any numerical or geometrical quantity or set of such quantities which may serve as reference or base for other quantities. Where the concept is geometric, the plural form is "datums" in contrast to the normal plural "data."

2.1 Reference Datums: from Wikipedia

A reference datum is a known and constant surface which can be used to describe the location of unknown points on the earth. Since reference datums can have different radii and can have different centre points, a specific point on the earth can have substantially different coordinates, depending on the datum used to make the measurement. There are hundreds of locally-developed reference datums around the world, usually referenced to some convenient local reference point. Contemporary datums, based on increasingly accurate measurements of the shape of the earth, are intended to cover larger areas. The common reference Datums in use are NAD27, NAD83, WGS84

The North American Datum of 1927 (NAD 27) is "the horizontal control datum for the United States that (was) defined by a location and azimuth on the Clarke spheroid of 1866, with origin at (the survey station) Meades Ranch." ... The geoidal height at Meades Ranch was assumed to be zero. "Geodetic positions on the North American Datum of 1927 were derived from the (coordinates of and an azimuth at Meades Ranch) through a readjustment of the triangulation of the entire network in which Laplace azimuths were introduced, and the Bowie method was used."

(<http://www.ngs.noaa.gov/faq.shtml#WhatDatum>) NAD27 is a local referencing system covering North America.

The North American Datum of 1983 (NAD 83) is "The horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980. "This datum, designated as NAD 83 ...is based on the adjustment of 250,000 points including 600 satellite Doppler stations which constrain the system to a geocentric origin." NAD83 may be considered a local referencing system.

WGS 84 is the World Geodetic System of 1984. It is the reference frame used by the U.S. Department of Defense (DoD) and is defined by the National Geospatial-Intelligence Agency(NGA) (formerly the National Imagry and Mapping Agency) (formerly the Defense Mapping Agency). WGS 84 is used by DoD for all its mapping, charting, surveying, and navigation needs, including its GPS "broadcast" and "precise" orbits. WGS 84 was defined in January 1987 using Doppler satellite surveying techniques. It was used as the reference frame for broadcast GPS Ephemerides (orbits) beginning January 23, 1987. At 0000 GMT January 2, 1994, WGS 84 was upgraded in accuracy using GPS measurements. The formal name then became WGS 84 (G730) since the upgrade date coincided with the start of GPS Week 730. It became the reference frame for broadcast orbits on June 28, 1994. At 0000 GMT September 30, 1996 (the start of GPS Week 873), WGS 84 was redefined again and was more closely aligned with International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) 94. It is now formally called WGS 84 (G873). WGS 84 (G873) was adopted as the reference frame for broadcast orbits on January 29, 1997.
(<http://www.ngs.noaa.gov/faq.shtml#WhatDatum>)

The WGS84 datum, which is almost identical to the NAD83 datum used in North America, is the only world referencing system in place today. WGS84 is the default standard datum for coordinates stored in recreational and commercial GPS units.

Users of GPS are cautioned that they must always check the datum of the maps they are using. To correctly enter, display, and to store map related map coordinates, the datum of the map must be entered into the GPS map datum field.

See related terms: (shape of the earth, geoid, ellipsoid, reference datum) For more detail - see <http://kartoweb.itc.nl/geometrics/Reference%20surfaces/body.htm>

2.2 Vertical datums: from Wikipedia

In North America - See "What are NGVD 29 and NAVD 88?"
<http://www.ngs.noaa.gov/faq.shtml#WhatDatum>

A vertical datum is used for measuring the elevations of points on the earth's surface. Vertical datums are either tidal, based on [sea levels](#), or geodetic, based on the same ellipsoid models of the earth used for computing horizontal datums.

In common usage, elevations are often cited in height above [sea level](#); this is a widely used tidal datum. Because ocean [tides](#) cause water levels to change constantly, the sea level is generally taken to be some [average](#) of the tide heights. Mean lower low water — the average of the lowest points the tide reached on each day during a measuring period of several years — is the datum used on most nautical charts, for example. While the use of sea-level as a datum is useful for geologically *recent* topographic features, sea level has not stayed constant throughout geological time, so is less useful when measuring very long-term processes. In some situations sea level does not apply at all -- for instance for [mapping Mars' surface](#) -- forcing the use of a different "zero elevation", such as mean radius.

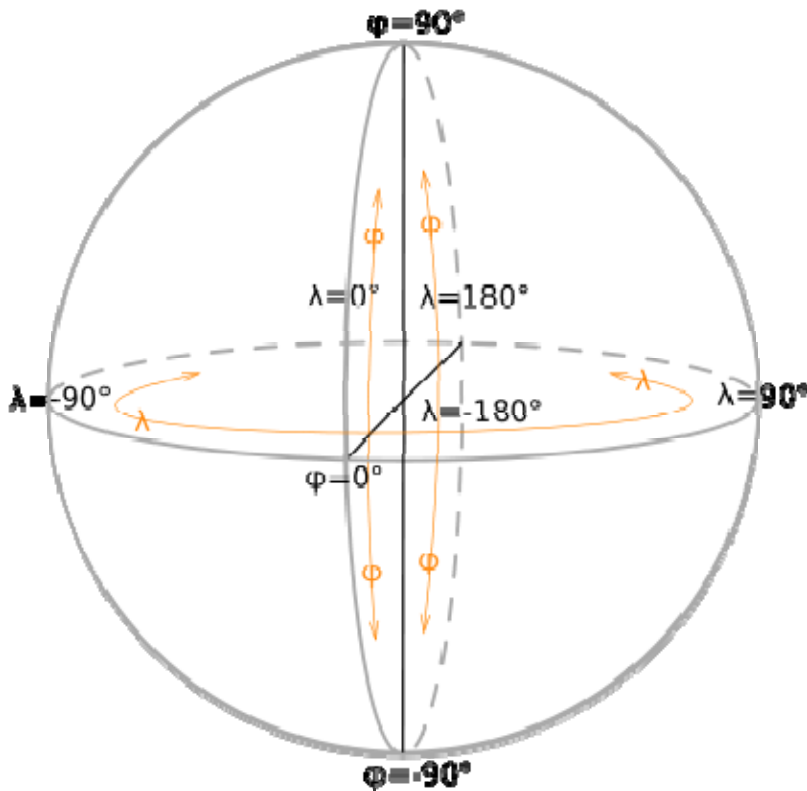
A geodetic vertical datum takes some specific zero point, and computes elevations based on the geodetic model being used, without further reference to sea levels. Usually, the starting reference point is a tide gauge, so at that point the geodetic and tidal datums might match, but due to sea level variations, the two scales may not match elsewhere. An example of a gravity-based geodetic datum is [NAVD88](#), used in North America, which is referenced to a point in [Quebec, Canada](#). Ellipsoid-based datums such as [WGS84](#), [GRS80](#) or [NAD83](#) use a theoretical surface that may differ significantly from the [geoid](#).

On [nautical charts](#), depths of water are relative to [chart datum](#) which is generally the lowest tide caused by [gravity](#) alone.

2.3 Geographic Coordinate System: mostly from Wikipedia

The Geographic System is not a projection, but a representation of a location on the earth's surface using spherical coordinates as measured in latitude and longitude.

2.3.1 First and second Dimensions: latitude and longitude



Latitude phi (φ) and Longitude lambda (λ)

Borrowing from theories of the ancient [Babylonians](#), later expanded by the famous [Greek](#) thinker and geographer [Ptolemy](#), a full circle is divided into 360 [degrees](#) (360°).

- [latitude](#) (abbreviation: Lat.) is the angle at the centre of the co-ordinate system between any point on the earth's surface and the plane of the [equator](#). Lines joining points of the same latitude are called [parallels](#), and they trace concentric circles on the surface of the earth. Each [pole](#) is 90 degrees: the [north pole](#) 90° N; the [south pole](#) 90° S. The 0° parallel of latitude is designated the equator, an imaginary line that divides the globe into the Northern and Southern Hemispheres.
- [longitude](#) (abbreviation: Long.) is the angle east or west, at the centre of the co-ordinate system, between any point on the earth's surface and the plane of an arbitrary north-south line between the two geographical poles. Lines joining points of the same longitude are called [meridians](#). All meridians are halves of great circles, and are not parallel: by definition they converge at the north and south poles. The line passing through the (former) [Royal Observatory, Greenwich](#) (near London in the [UK](#)) is the international zero-longitude reference line, the [Prime Meridian](#). The [antipodal](#) meridian of Greenwich is both 180° W and 180° E.

By combining these two angles, the horizontal position of any location on Earth can be specified.

For example, [Baltimore, Maryland](#) (in the [USA](#)) has a latitude of 39.3° North, and a longitude of 76.6° West ([39.3° N 76.6° W](#)). So, a vector drawn from the center of the earth to a point 39.3° north of the equator and 76.6° west of Greenwich will pass through Baltimore.

This latitude/longitude "webbing" is known as the common *graticule*.

Traditionally, degrees have been divided into [minutes](#) (1/60th of a degree, designated by ' or "m") and [seconds](#) (1/60th of a minute, designated by " or "s"). There are several formats for degrees, all of them appearing in the same Lat-Long order:

- **DMS** Degree:Minute:Second (49°30'00"-123d30m00s)
- **DM** Degree:Minute (49°30.0'-123d30.0m)
- **DD** Decimal Degree (49.5000°-123.5000d), generally with 4 decimal numbers.

To convert from DM or DMS to DD, decimal degrees = whole number of degrees, plus minutes divided by 60, plus seconds divided by 3600. DMS is the most common format, and is standard on all charts and maps, as well as global positioning systems and geographic information systems.

The equator is the [fundamental plane](#) of all geographic coordinate systems. All spherical coordinate systems define such a fundamental plane.

Latitude and longitude values can be based on several different [geodetic systems](#) or [datums](#), the most common being the [WGS 84](#) used by all GPS equipment. In other words, the same point on the earth's surface can be described by different latitude and longitude values depending on the reference datum.

In popular GIS software, data projected in latitude/longitude is often specified via a 'Geographic Coordinate System'. For example, data in latitude/longitude with the [datum](#) as the [North American Datum of 1983](#) is denoted by 'GCS_North_American_1983'.

2.3.2 Third dimension: altitude, height, depth

To completely specify a location on, in, or above the earth, one has to also specify the elevation, defined as the vertical position of the location relative to the centre of the reference system or some definition of the earth's surface. This is expressed in terms of the vertical distance to the earth below, but, because of the ambiguity of "surface" and "vertical", is more commonly expressed relative to a more precisely defined [datum](#) such as [mean sea level](#) (as height [above mean sea level](#)) or a [geoid](#) (a mathematical model of the shape of the earth's surface). The distance to the earth's center can be used both for very deep positions and for positions in space.

Other terms used with respect to the distance of a point from the earth's surface or some other datum are [altitude](#), [height](#), and [depth](#).

3. Map Projections

The latitude and longitude values in the Geographic System cannot be used for directly determining basic information such as distance or direction between two points. While the distance between degrees in latitude remain fairly constant over the earth, one degree in longitude is much longer near the equator than it is near the poles (111 km at the equator versus 19 km at 80°).

For many applications the locations represented by the Geographic System are converted into other projects. The particular application can motivate the choice of a map projection. For many applications it is reasonable to use an equal area projection

3.1 Major classes of projections

At least 250 different projections have been devised and described by cartographers (Gaus).

Projections fall into four major classes: cylindrical, conical, azimuthal, and miscellaneous.

Cylindrical projections result from projecting a spherical surface onto a cylinder.

Conic projections result from projecting a spherical surface onto a cone.

Azimuthal projections result from projecting a spherical surface onto a plane.

The cylindrical, conical and azimuthal projections are developable surfaces. After a suitable straight line cut, cylindrical and conical surfaces can be flattened to a plane without tearing. The azimuthal surface is already a plane. This flattening without tearing characterizes developable surfaces.

Factors describing projections often include the orientation and size of the developable surfaces relative to the sphere. Tangent cylindrical projections are described as normal, transverse and oblique for tangency at the equator, at the poles, or at other great arcs, respectively.

Secant cylindrical projections involve a smaller diameter cylinder so cut the sphere. Envision the graticule (latitude and longitude lines) for the sphere. The normal and transverse cylinders will cut the sphere at two latitudes or two meridians respectively. A similar description applies to cones. The Albers equal area conic projection is defined by the two parallels (latitudes) lines where the cone cuts the earth. This USGS uses this projection for its state maps and all U. S. maps of 1:2,500,000 scale or smaller. It is useful for representing areas that have a predominant east-west expanse, such as the

conterminous United States. For such equal area maps, all areas on the map are proportional to the same areas on a globe, directions are reasonably accurate in limited regions, and distances and scale are true only along the standard parallels.

Tangent planar projections are described as equatorial, polar, or oblique depending on where the plane touches the earth. Projection from the center of the earth is called gnomonic. The projection from the point on the opposite side of the earth from the point of tangency is called stereographic. The orthographic projection extends the graticule to the plane along lines perpendicular to the plane.

Map projections make difference compromises as they distort the surface of the earth to provide a rendering on a plane. Some of this can be observed by projecting the graticule (latitude and longitude lines) onto the developable surface. In many instances the impression is that the distortion is less when the developable surface is closer to the sphere surface. Tissot's indicatrix provides a view of the distortion near at a point. This shows how a circle around a point on the sphere looks in the map projection. Showing local distortion at many locations on the sphere helps to provide insight about map distortion.

3.2 Map Projection Properties

Equidistant: Equidistant maps show the true distance only from the center of the projection or along a special set of lines. A azimuthal equidistant map centered at Washington D. C. would show the correct distance between Washington D.C and any other point on the projection, but not, for example, the correct distance between San Diego and Seattle. No such equidistant flat map project can be an equal area projection.

Equal areas: A map project is equal area if every part, as well as the whole has the same areas as the corresponding parts on the Earth if reduced to the same scale. No equal are flat map is also conformal

Conformal: A conformal map projection has the scale the same in all direction for any given point. Consequences of this are that meridians and parallels intersect at right angles. Also the shapes of very small areas and angles with very short sides are preserved. (The size of most areas however is distorted.)

3.3 Map Scale

The map scale = distance on a map / distance on the ground. Verbally we might say 1 inch represents 2000 feet. If the units of measure are the same the ratio is unitless.

In comparing a 1/500,000 map to a 1/24,000 map, the fraction 1/24,000 is larger so the 1/24,000 map is called a larger scale map. Some people get confused when they focus attention on the denominator rather than on the fraction. If we enlarged a map to twice its height and width, the enlarged map would be the larger scale map. The enlarging would change the numerator from 1 to 2. Dividing both numerator and denominator by 2, to

represents the scale in a canonical form with 1 in the numerator makes the denominator gets smaller.