Online Surveying FE 208
Lecture 22

Coordinate Systems

Learning Objectives for this Lecture

1. **Know the major terms used with reference to coordinate systems**
2. **Understand "The Problem with the shape of the Earth"**
3. **Have an understanding of the major ellipsoids used**
4. **Know the UTM and State Plane coordinate systems**
5. **Know the NAD27 and NAD83 datums**

<u>Terms to Know</u>

Geoid - is the "mathematical figure of the Earth", a smooth but highly irregular surface that corresponds not to the actual surface of the Earth's crust, but to a surface which can only be known through extensive gravitational measurements and calculations.

Ellipsoid - In geodesy, a **reference ellipsoid** is a mathematically-defined surface that approximates the geoid, the truer figure of the Earth, or other planetary body. Because of their relative simplicity, reference ellipsoids are used as a preferred surface on which geodetic network computations are performed and point coordinates such as latitude, longitude, and elevation are defined.

Coordinate System - A **geographic coordinate system** is a coordinate system that enables every location on the Earth to be specified by a set of numbers or letters. The coordinates are often chosen such that one of the numbers represents vertical position, and two or three of the numbers represent horizontal position. A common choice of coordinates is latitude, longitude and elevation.[1]

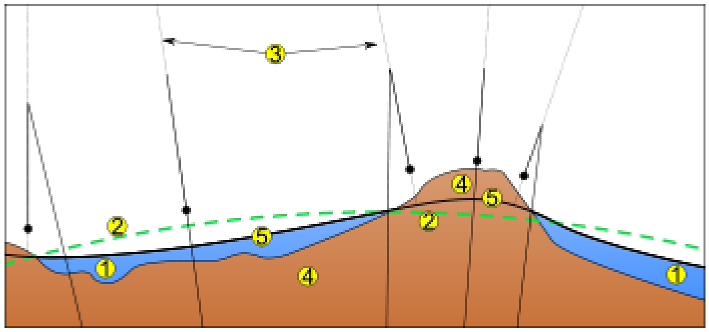
Latitude - The latitude (abbreviation: Lat., φ, or phi) of a point on the Earth's surface is the angle between the equatorial plane and a line that passes through that point and is normal to the surface of a reference ellipsoid which approximates the shape of the Earth.[n 1] This line passes a few kilometers away from the center of the Earth except at the poles and the equator where it passes through Earth's center.[n 2] Lines joining points of the same latitude trace circles on the surface of the Earth called parallels, as they are parallel to the equator and to each other. The north pole is 90° N; the south pole is 90° S. The 0° parallel of latitude is designated the equator, the fundamental plane of all geographic coordinate systems. The equator divides the globe into Northern and Southern Hemispheres.

Longitude - The Longitude (abbreviation: Long., λ, or lambda) of a point on the Earth's surface is the angle east or west from a reference meridian to another meridian that passes through that point. All meridians are halves of great ellipses (often improperly called great circles), which converge at the north and south poles.

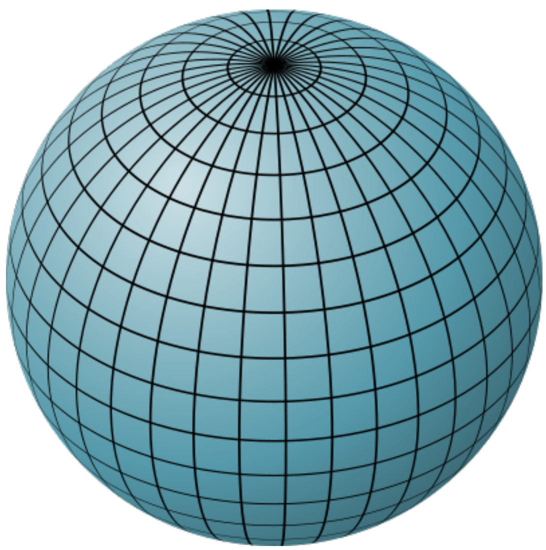
Map Projection - A **map projection** is a systematic transformation of the latitudes and longitudes of locations on the surface of a sphere or an ellipsoid into locations on a plane.[1] Map projections are necessary for creating maps. All map projections distort the surface in some fashion. Depending 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. There is no limit to the number of possible map projections.

Universal Trans Mercator - The Universal Transverse Mercator coordinate system was developed by the United States Army Corps of Engineers in the 1940s.[1] The system was based on an ellipsoidal model of Earth. For areas within the contiguous United States the Clarke 1866 ellipsoid[2] was used. For the remaining areas of Earth, including Hawaii, the International Ellipsoid[3] was used. The WGS84 ellipsoid is now generally used to model the Earth in the UTM coordinate system, which means current UTM northing at a given point can be 200+ meters different from the old. For different geographic regions, other datum systems (e.g.: ED50, NAD83) can be used.

State Plane - The **State Plane Coordinate System (SPS** or **SPCS)** is a set of 124 geographic zones or coordinate systems designed for specific regions of the United States. Each state contains one or more state plane zones, the boundaries of which usually follow county lines. There are 110 zones in the continental US, with 10 more in Alaska, 5 in Hawaii, and one for Puerto Rico and US Virgin Islands. The system is widely used for geographic data by state and local governments. Its popularity is due to at least two factors. First, it uses a simple Cartesian coordinate system to specify locations rather than a more complex spherical coordinate system (the geographic coordinate system of latitude and longitude). By thus ignoring the curvature of the Earth, "plane surveying" methods can be used, speeding up and simplifying calculations. Second, the system is highly accurate within each zone (error less than 1:10,000). Outside a specific state plane zone accuracy rapidly declines, thus the system is not useful for regional or national mapping.



1. Ocean
2. Reference ellipsoid
3. Local plumb line
4. Continent
5. Geoid

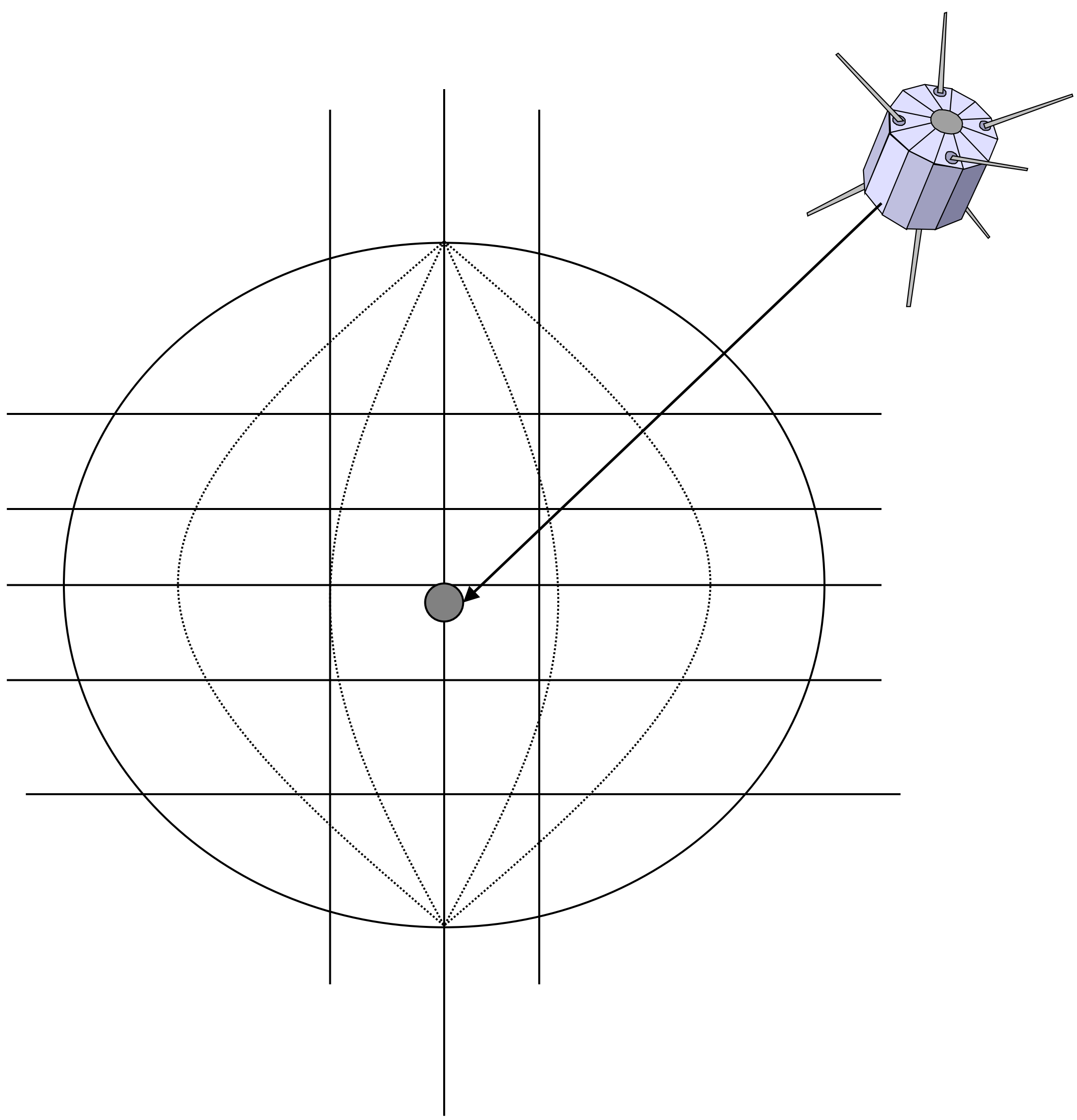


A graticule on a sphere or an ellipsoid. The lines from pole to pole are lines of constant longitude, or **meridians**. The circles parallel to the equator are lines of constant latitude, or **parallels**. The graticule determines the latitude and longitude of position on the surface.

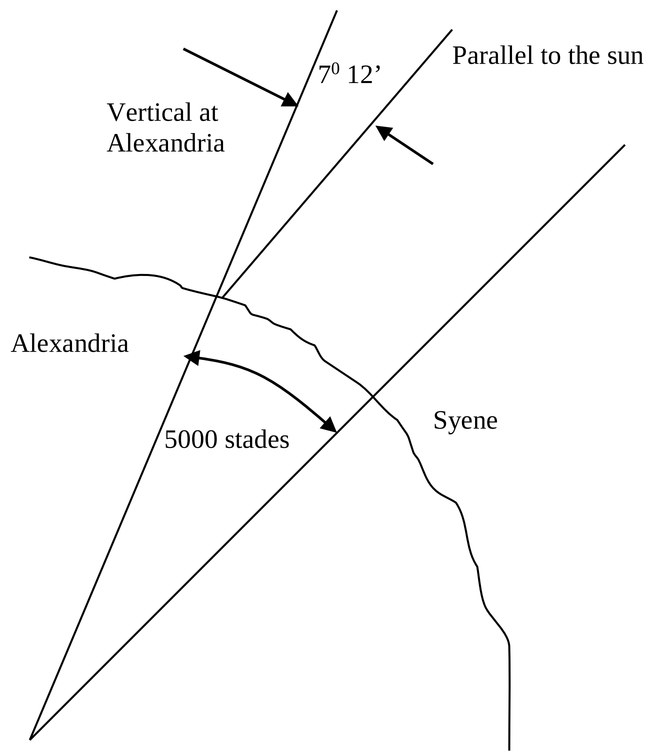
The shape of the earth

Problem:

- GPS satellites are referenced to the mass center of the earth
- Geodetic surveyors want to reference to latitude and longitude with reference to a particular datum
- Land surveyors want rectangular coordinates, in feet, in addition to elevation.



Eraosthenes solution - spherical



7^0 12’ = 1/50 of a circle

Therefore the circumference is 5000 stades x 50 = 250000 stades

Approximately 52500km to 39400 km. The accepted value today is about 40000 km.

Newton – 1687

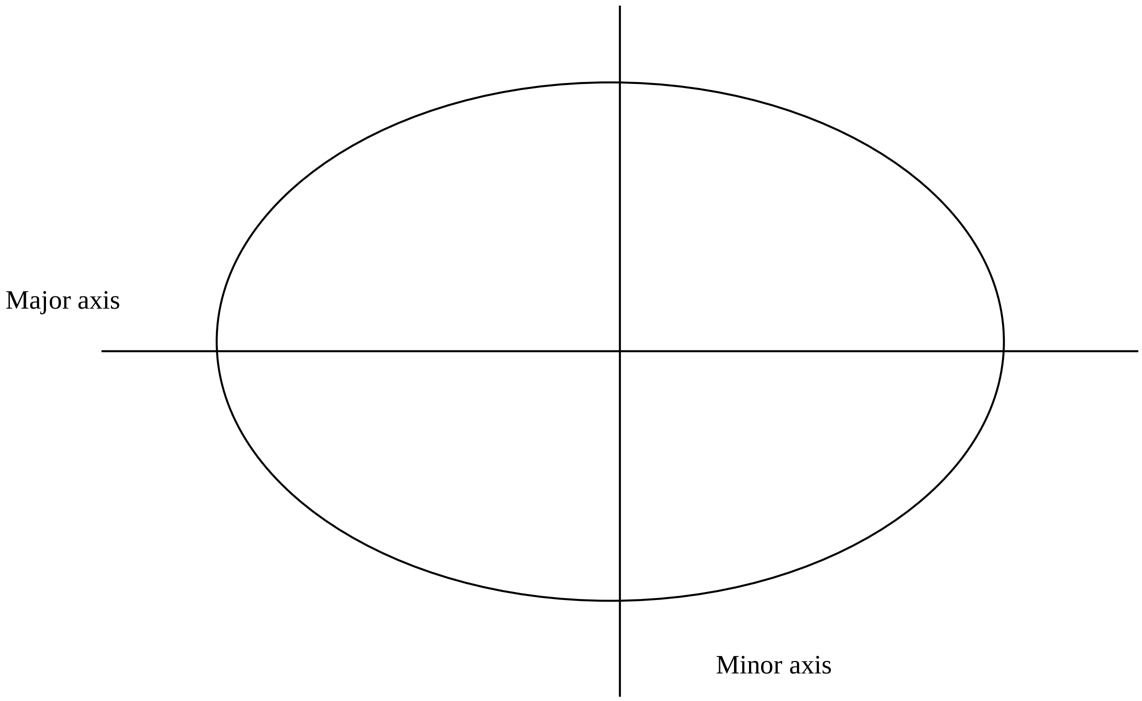
Computes the Earth to be an oblate spheriod – Flattened at the poles

The Cassinis – 1700’s

Compute the Earth to be a prolate spheriod – Flattened at the equator

1735 expedition finds the length of 1^0 of arc to be longer at the north pole (Approx.) than at the equator thus the Earth is declared an oblate spheriod as Newton computed.

Much of the mathematical difficulty is removed if the Earth model is assumed to be an ellipse.



Using measurements of arcs at points on the Earth the ellipsoid parameters have been calculated.

a = semi-major axis
b = semi-minor axis

f = flattening ratio = (a-b) / a

These ellipsoids are not Earth mass centered, therefore the calculations will vary by as much as 200 meters.

Common ellipsoids used:

Ellipsoid	a (meters)	1/f
Everest 1830	6377276.3452	300.801700
Bessel 1841 (USSR, Sumatra, Borneo, Japan, etc.)	6377397.1550	299.152813
Clarke 1866 (U.S., Canada, Central Am., Philippines)	6378206.4000	294.978698
Clarke 1880 (France, Africa)	63782491450	293.465000
International 1924 (South Am., Europe, Australia, China, Antarctica	6378388.0000	297.000000

The Clarke spheroid model fit the Atlantic coast of the U.S. better and so was adopted.

In 1927 a readjustment for latitude and longitude was made for the U.S. and the datum was referred to as the North American Datum of 1927.

With the advent of satellites and other technologies, the ellipsoid calculations have been recomputed for being at or very near the Earth's mass center.

Coordinate system	Reference ellipsoid	a (meters)	1/f
AGD	AN (or SA-69)	6378160	298.25
ED-79	International	6378388	297
GEM-8	GEM-8	6378145	298.255
GEM-9 (OR GEM-10)	GEM-9 (OR GEM-10)	6378140	298.255
GEM-10B	GEM-10B	6378138	298.257
GEM-T1	GEM-T1	6378137	298.257
NAD-27	**Clarke 1866**	**6378206.4**	**294.9786982**
NAD-83	**GRS-80**	**6378137**	**298.257222101**
NWL-9D = NSWC-9Z2	WGS-66	6378145	298.25
SA-69	SA-69 (or AN)	6378160	298.25
WGS-72	**WGS-72**	**6378135**	**298.26**
WGS-84	**WGS-84**	**6378137**	**298.257223563**

The current system used in the U.S. is NAD-83.
GPS for all practical purposes uses WGS-84 which is nearly the same.

Surveys of less than 12 – 150 square miles can assume the Earth's surface to be flat – **Plane Surveying**

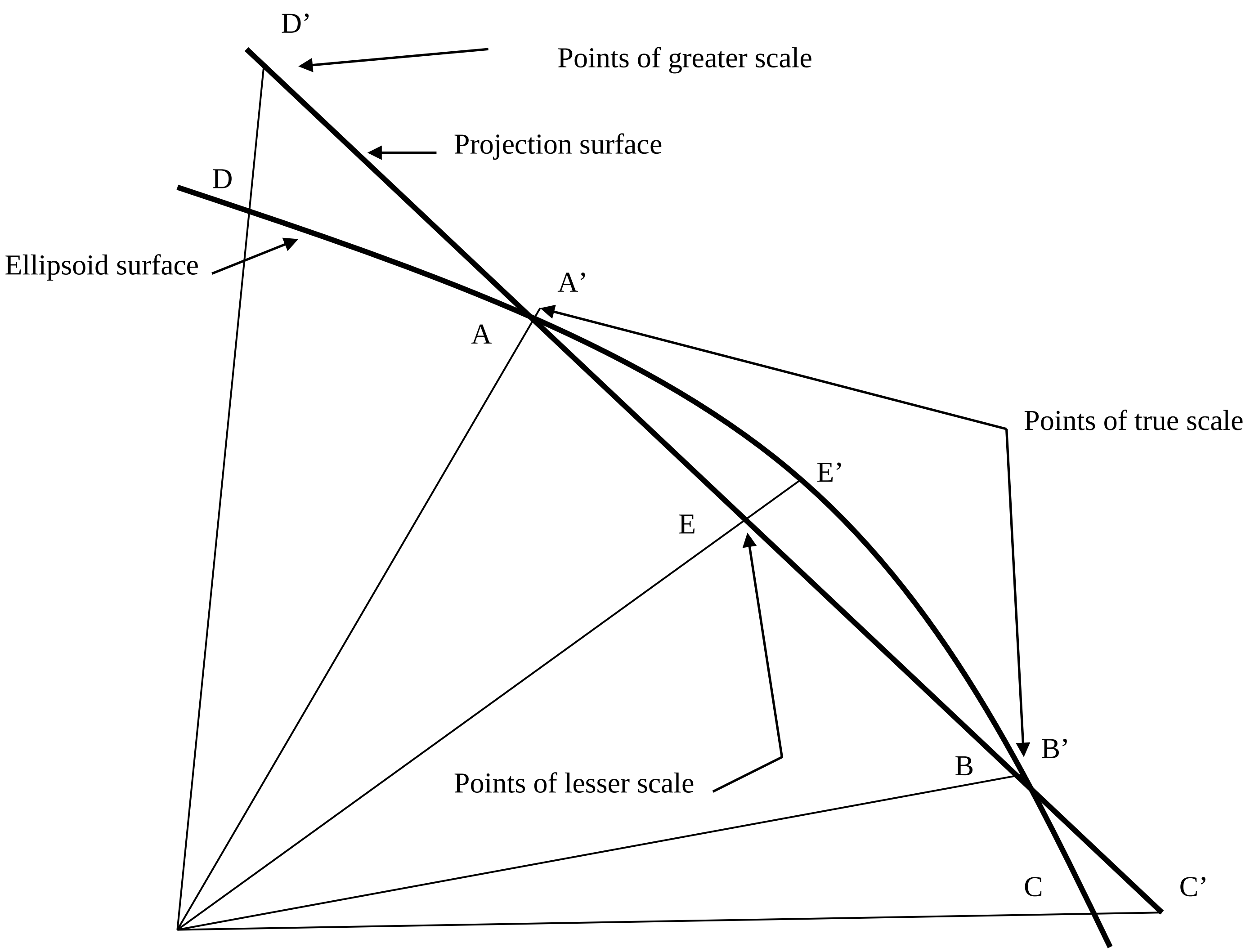
The National Geodetic Survey (NGS) met this requirement with the State Plane System of coordinates.

- Provides a common datum for reference for horizontal control of all surveys in a large area
- Eliminates individual surveys based on assumed coordinates

The state plane rectangular grid is fit to a "developed" surface

2 projections are used for state plane coordinates

- Lambert conformal conic projection – utilizes an imaginary cone for the development
- Transverse Mercator projection – uses an imaginary cylinder for the development



These distortions are held to a minimum by choosing a conformal fit and by limiting the zone of coverage to a maximum of 158 miles with a 2/3 thirds overlap.

Distortions are 1 : 10000 or less

- Scales vary north to south but not east to west.
- Zones are therefore north south.
- Oregon has 2 zones

NAD27 and NAD83

- The state plane location of points is referenced to a geodetic latitude and longitude
- The geodetic latitude and longitude are referenced to specific ellipsoid models and datums

NAD27 – North American Datum of 1927

Referenced to the Clarke ellipsoid of 1866

Datum	Reference	a	1/f
NAD-27	Clarke 1866	6378206.4	294.9786982

NAD83 – North American Datum of 1983

Referenced to the Clarke ellipsoid of 1866

Datum	Reference	a	1/f
NAD-83	GRS-80	6378137	298.257222101

Computing state plane coordinates from geographic positions

$X = R \sin \theta + C$

$Y = R_b – R \cos \theta$

Grid azimuth = geodetic azimuth - θ + second term

Where:

R = the radius for the latitude of the station

R_b = a constant for the zone

θ = the mapping angle for the longitude of the station

C = the value of x assigned for the Central Meridian for a zone

The second term is ignored for work less than 5 miles

Example

Station

Latitude 44^0 24’ 25.943”
Longitude 119^0 46’ 26.562”

R = 21889817.34 (interpolated from tables)

θ = 0^0 29’ 47.9768” (interpolated from tables)
For Oregon south C = 2,000,000.00

X = 2189746.36

Y = 999672.21