BLUE MARBLE GEOGRAPHICS

Geodesy Primer: Datums & Projections

Sam Knight
Director of Product Management,
Blue Marble Geographics

Training Agenda

- 9:00 to 11:00 (Break @10:00):
- 2:00 to 4:00 (Break @3:00):
- Introductions
- Geodesy
  - Coordinate Systems
  - Datum Transformations
  - Map Projections

BLUE MARBLE GEOGRAPHICS

Geodesy

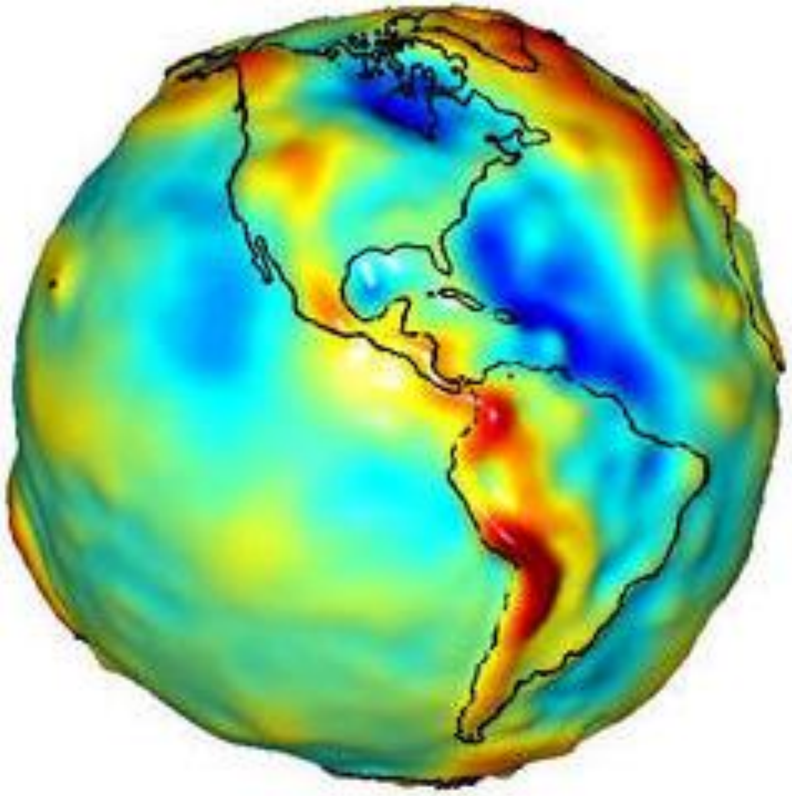
What is Geodesy?

- The science of measuring the size and shape of the Earth
- Determination of the exact position of points on its surface
- *How that changes over time*

BLUE MARBLE GEOGRAPHICS

Size & Shape

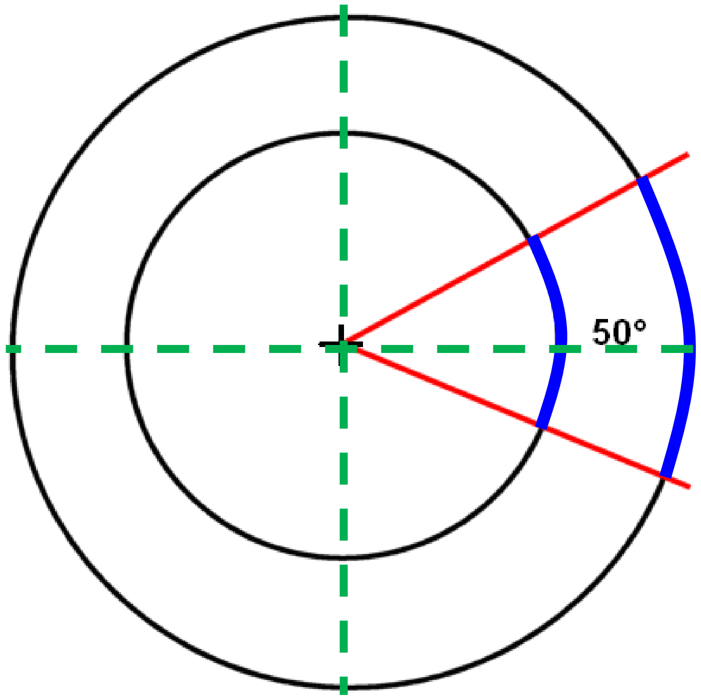
- Earth is a *Pseudo-spheroid* roughly 6,357km in radius
  - It's wider at the Equator than the poles
  - The surface undulates



BLUE MARBLE GEOGRAPHICS

Coordinates

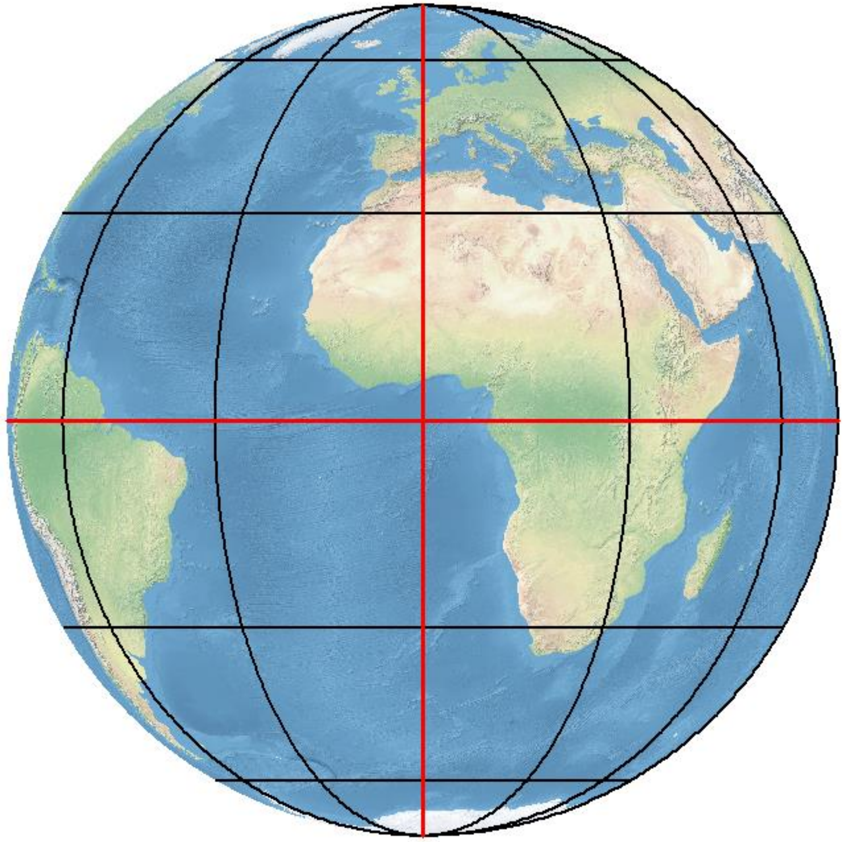
- What are Coordinates?
  - A set of numbers used to represent points in space
  - Measures relative to an **Origin** and Axes
  - Depending on the coordinate system, coordinates can be displayed in various formats of various units.
- Units
  - Angular
    - In Geodetic Coordinate Systems, coordinates are given in angular units, the most common being Degrees.
    - Angular units can be displayed in a number of formats
  - Linear
    - Cartesian and Projected coordinate systems use linear measures
    - Unit format is mostly limited to decimal precision.



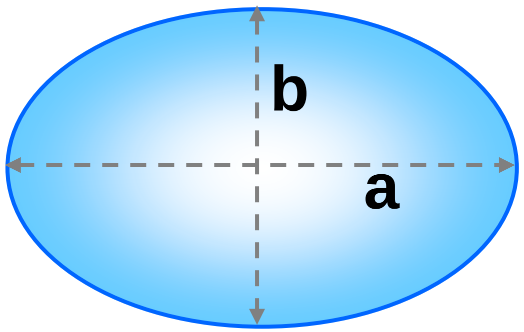
BLUE MARBLE GEOGRAPHICS

Geodetic Coordinate Systems

- Globes are the most accurate maps we have
- All geodetic systems use Latitude and Longitude to define the positions on the Earth. These are angular measurements, not linear
- The two main reference lines from which all distances and locations are calculated are the **Equator** and the **Prime Meridian**



Ellipsoid

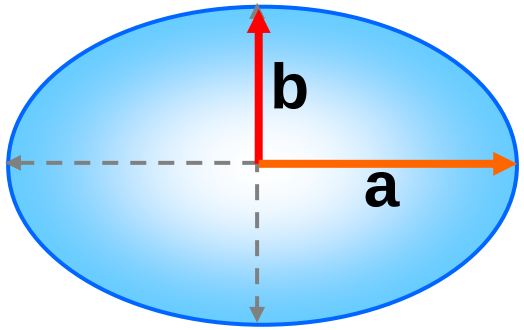


- Sir Isaac Newton popularised the non-spherical shape of the Earth into public awareness. He concluded that the Earth was an "oblate ellipsoid of revolution" – an ellipse wider at the equator than at the poles.

- At the equator, the diameter of the Earth is ~7927 miles (~12,756km). At the poles, the diameter is almost 7900 miles (12,713km). 27 miles, a difference of 0.34% is just enough to give map makers a headache.

- If it weren't for Flattening, mapping would be as easy as **Pi**.

Flattening



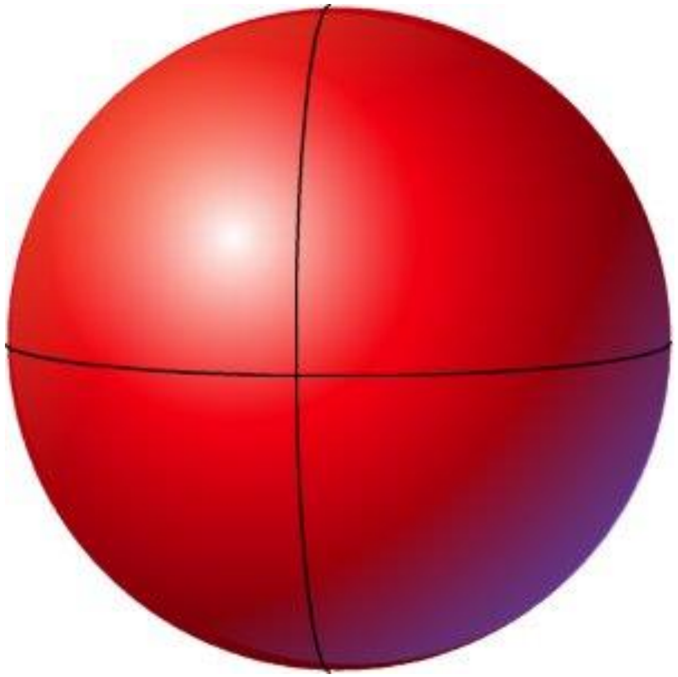
Flattening is the ratio of the difference between the Semi-Major Axis, and the Semi-Minor Axis.

$$f = (a-b)/a$$
$$1/f = a/(a-b)$$

Ellipsoid	**Radius to Equator**	**1/f**	**Region**
Plessis 1817	6,376,523 meters	308.64	France
Bessel 1841	6,377,397 meters	299.15	Japan
Airy 1830	6,377,563 meters	299.32	UK
GRS80/WGS84	6,378,137 meters	298.26	World
Clarke 1866	6,378,206 meters	294.98	North America
Clarke 1880	6,378,206 meters	293.46	France, Africa
SLC95	6,378,523 meters	298.28	St Louis County, MN

BLUE MARBLE GEOGRAPHICS

Horizontal Datums



- A datum is a “mappable surface” defined by an ellipsoid with a base-point and a reference meridian.
- A datum takes your ellipsoid and gives it an origin, tying it to the earth at one spot.
- One point on the Earth can have many different coordinates, depending on the datum being used.

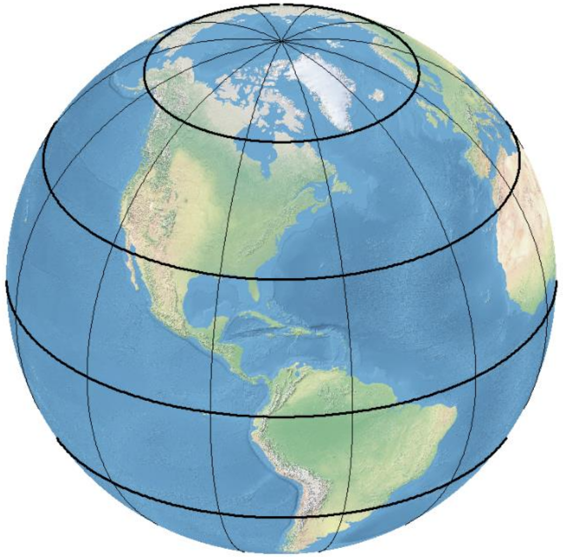
- You can have an ellipsoid without it being a datum.
- You **CAN NOT** have a datum without an ellipsoid!

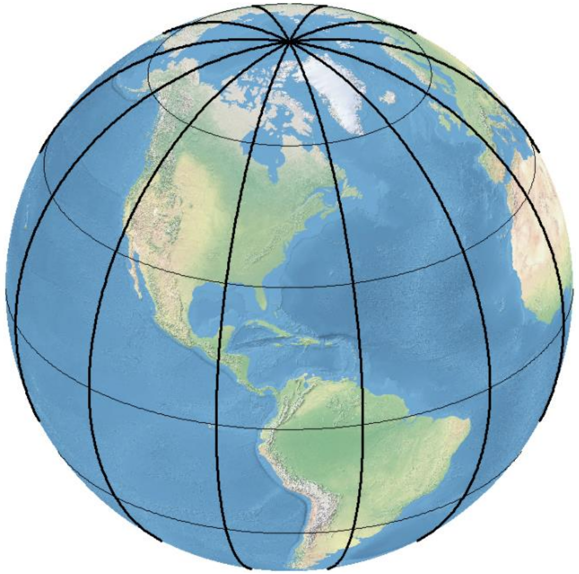
BLUE MARBLE GEOGRAPHICS

The Equator & Prime Meridian

The Equator

- The Equator divides the Earth in half with an imaginary line that runs East/West around the middle of the globe.
- All similar lines running parallel to the equator at constant increments are called lines of **Latitude.**
- Also referred to as parallels, they run 90 degrees north and 90 degrees south of the equator and they never intersect with each other.





The Prime Meridian

- The Prime Meridian is a mostly imaginary (and arbitrary) line that runs North/South, dividing the Earth in half from pole to pole. (Est. 1851 by Sir George Airy; standardized in 1884.)
- It runs through the Royal Observatory of Greenwich, England and is also known as the *Greenwich Meridian*.
- All similar lines running North/South through the poles are called lines of **Longitude.**
- They are farthest apart at the equator and converge at the poles.

BLUE MARBLE GEOGRAPHICS

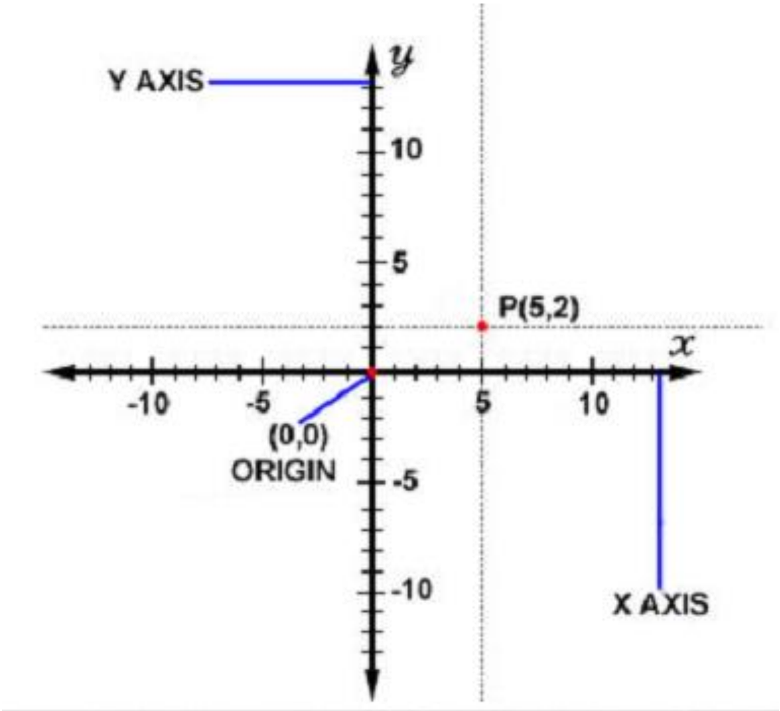
Degrees

- How "Big" is a Degree?
  - One degree of **longitude** on the surface of Earth at the equator is approximately 69.17mi (111.32km)
  - At the North/South Pole, it is 0 miles
  - Degrees are not constant distances on the surface like linear measurements
- Different Formats
  - Degrees Minutes Seconds, Decimal Minutes, Decimal Degrees are some of the more common degree formats

44° 13' 36.96" N, 69° 46' 29.11" W	Degrees Minutes Seconds
44° 13.616', -69° 46.485'	Decimal Minutes
44.226933, -69.774753	Decimal Degrees
44.133696, -69.462911	DMS
44.136160, -69.464851	DM
44133696, -069462911	Packed DMS
44136160, -069464851	Packed DM

BLUE MARBLE GEOGRAPHICS

Cartesian & Projected Systems

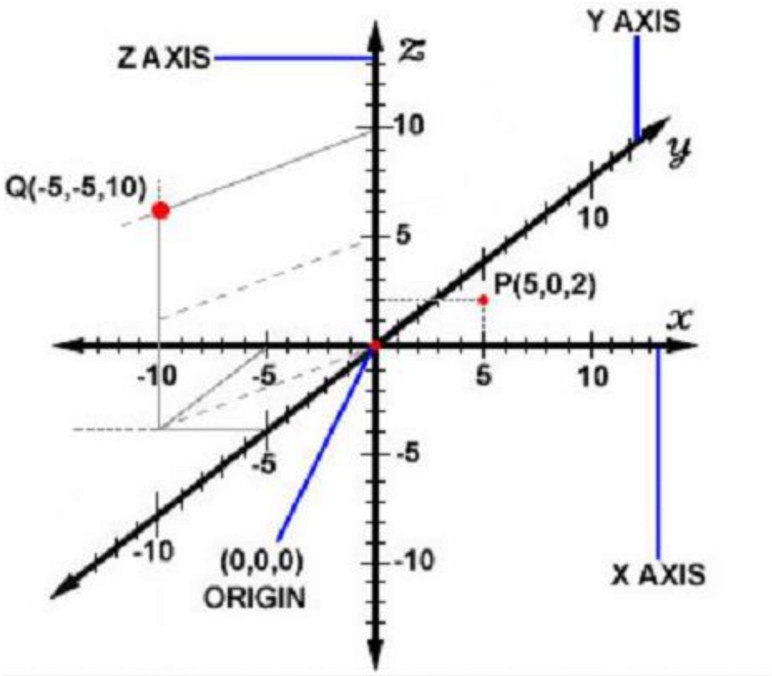


2 DIMENSIONAL CARTESIAN COORDINATE SYSTEM

- A two or three dimensional coordinate system in which, in the top example, X measures East/West distance and Y measures North/South distance.

- Each point on the plane is defined by an X, Y, and sometimes Z coordinate pair. The point of intersection where the axes meet, is called the origin.

- Relative measures of distance, area, and direction are linear, and constant throughout the Cartesian system.

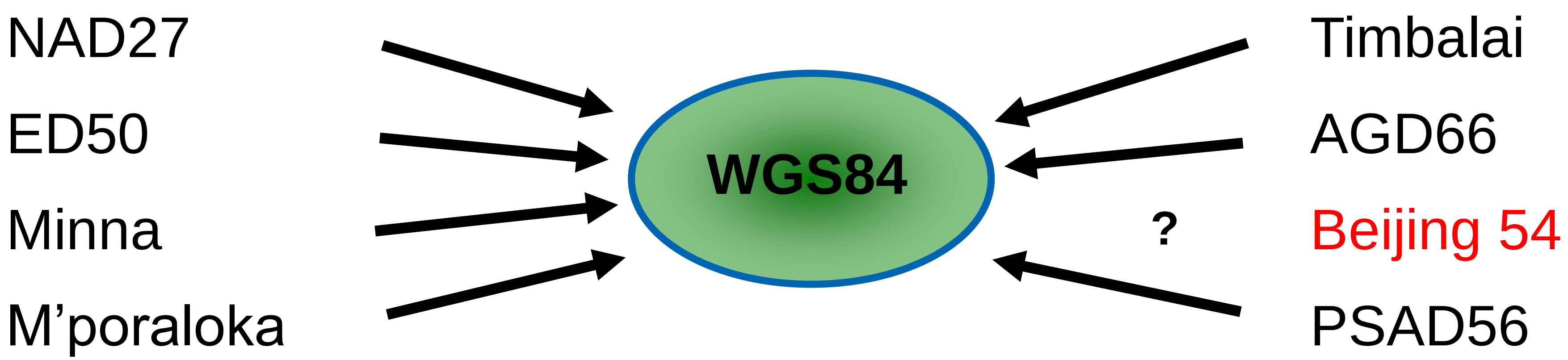


3 DIMENSIONAL CARTESIAN COORDINATE SYSTEM

BLUE MARBLE GEOGRAPHICS

WGS84 Ellipsoid/Datum

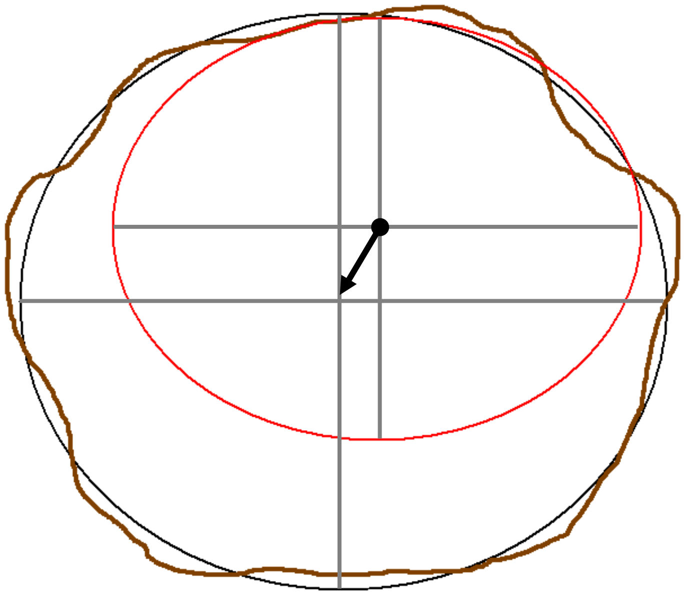
- World Geodetic System of 1984 is a standard ellipsoid definition worldwide
  - Earth-centered, a "best fit" for the whole earth
  - Originally created as Geodetic Reference System of 1980 by the US Defense Mapping Agency
  - Used as the basis worldwide for the GPS satellite network
  - It serves as a common ellipsoid/datum through which we convert most other datums



BLUE MARBLE GEOGRAPHICS

Datum Transformations

- When coordinates exist on one datum, and the need exists to plot or display them based on another, a datum **transformation** is required.



3 Parameter shift (Molodensky, Geocentric):

- When performing a 3 parameter datum transformation, a linear shift is applied to the x, y, and z axes at the geocenter.
- Accuracy can be +/- 1 to 50 meters.
- Does not model network distortions well.
- But, they are easy to calculate!

7 Parameter Shift (Bursa-Wolfe, Helmert):

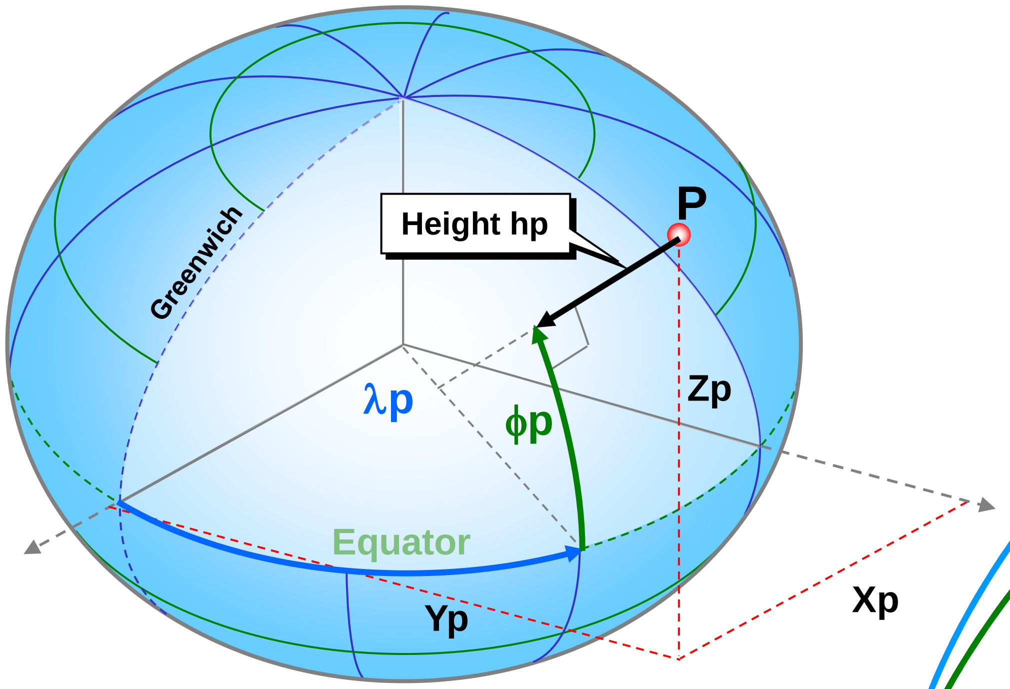
- The same x,y,z shift found in the Molodensky method, but with 3 additional parameters of rotations of the axes and a scale.
- If applied properly can allow for more accurate mapping of +/- 1m over large areas.
- Rotation sense is **critical**

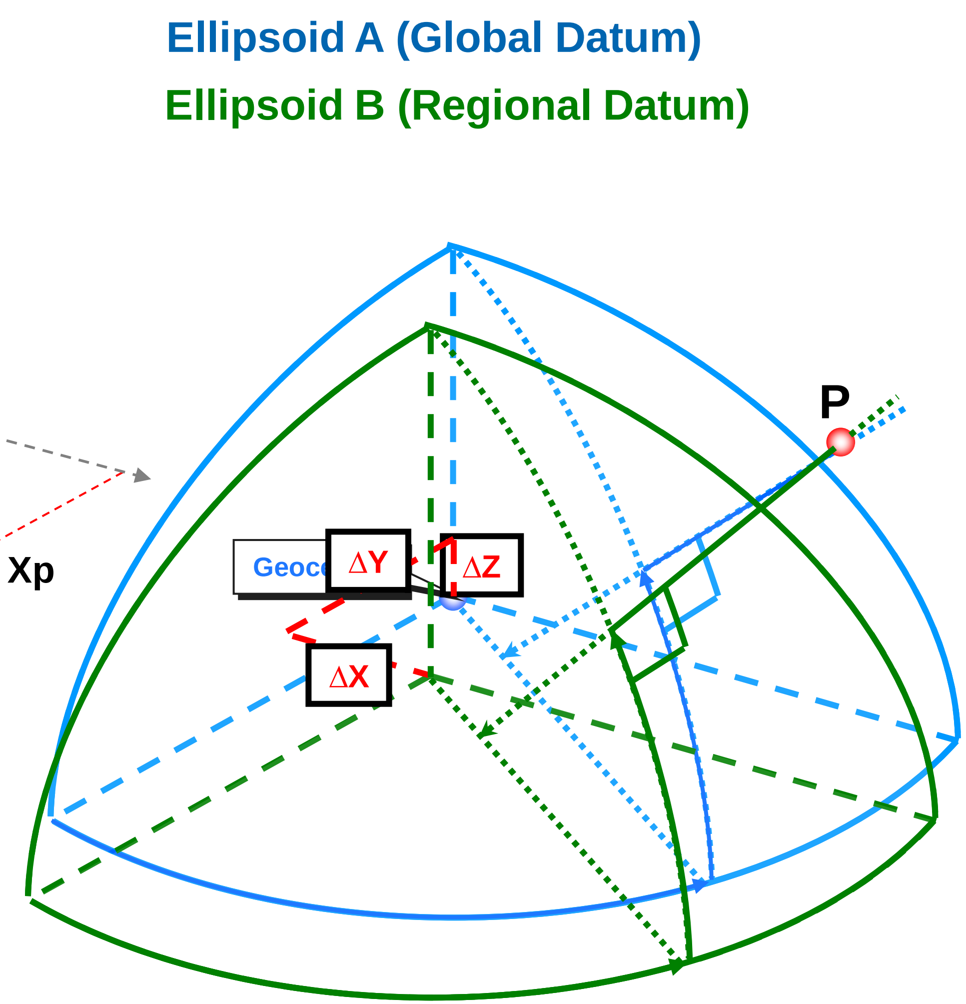
Other Transformation Methods (High Accuracy):

- Molodensky-Badekas 10 parameter (Rare)
- NADCON, HARN, NTv2, OSTN02, etc: (Gridded data tables)

BLUE MARBLE GEOGRAPHICS

What is a datum shift really?





Blue Marble Geographics

Datum Transformations – Example

NAD 27 to WGS84

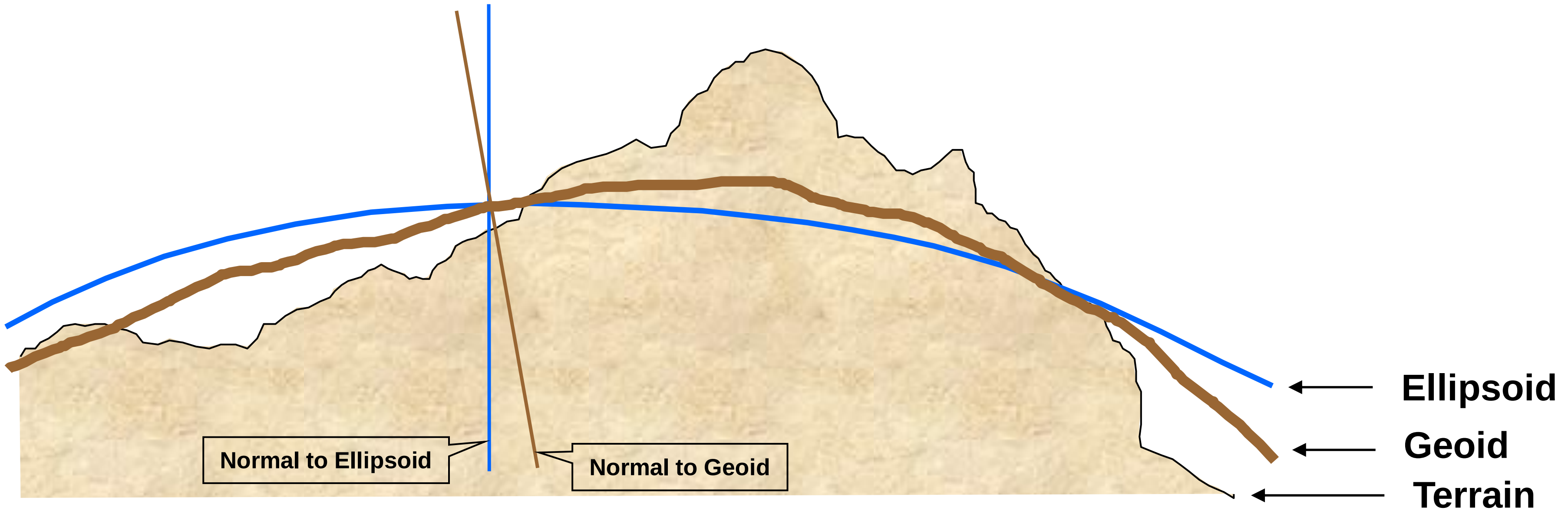
- NADCON (15cm)
- MRE (3m)
- Canadian NTv2 (3m)
- Molodensky
  - East US (13m)
  - Continental US (14.5m)

BLUE MARBLE GEOGRAPHICS

Vertical Datums

Geoid Model

- A **zero** surface to which elevations or heights are referred.
- Irregular surface model of the Earth that takes into account an average calculation of elevation factoring in ocean depth, gravimetric readings, and terrestrial height.



BLUE MARBLE GEOGRAPHICS

Geoids and Mean Sea Level

Geoid Model vs. MSL

- Not the same thing!
- Vertical models are *approximations* of MSL
  - Some are not sea level at all, but are actually tidal offsets, or some other local reference
- MSL is a “moving target”
  - For highest accuracy, local vertical deflections must be taken into account

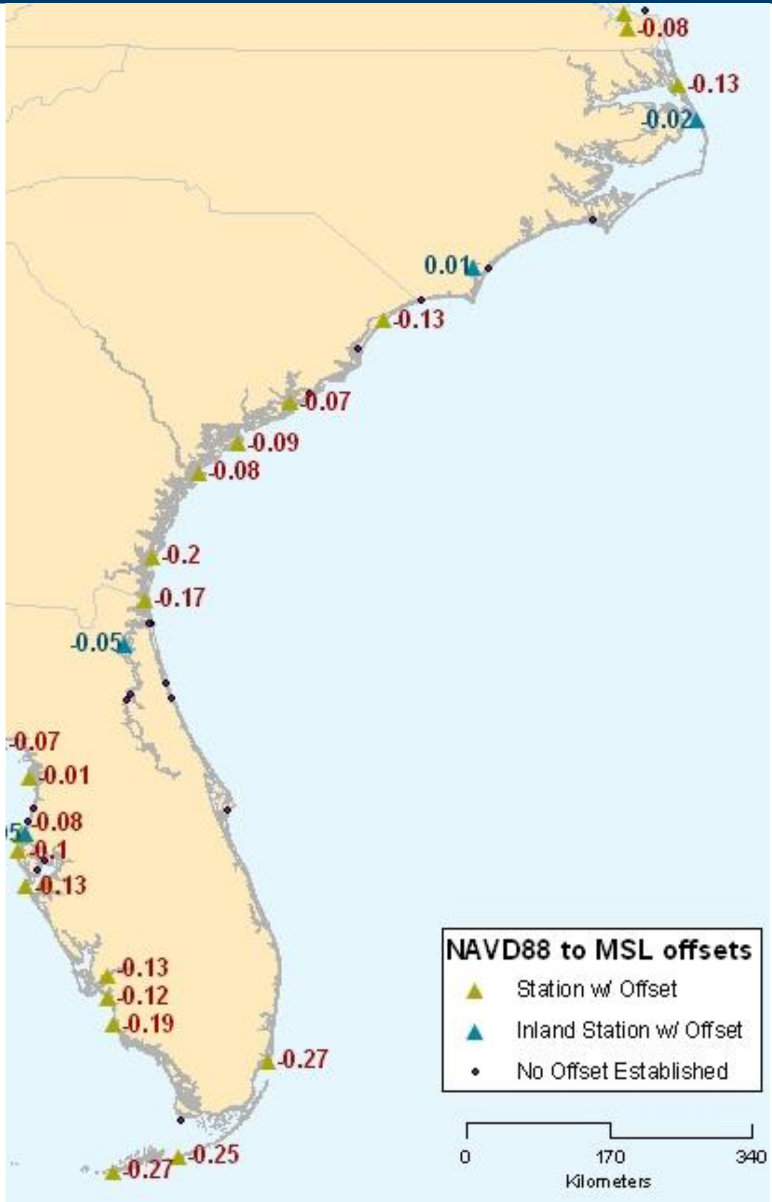


Image Courtesy of Seacoos.org

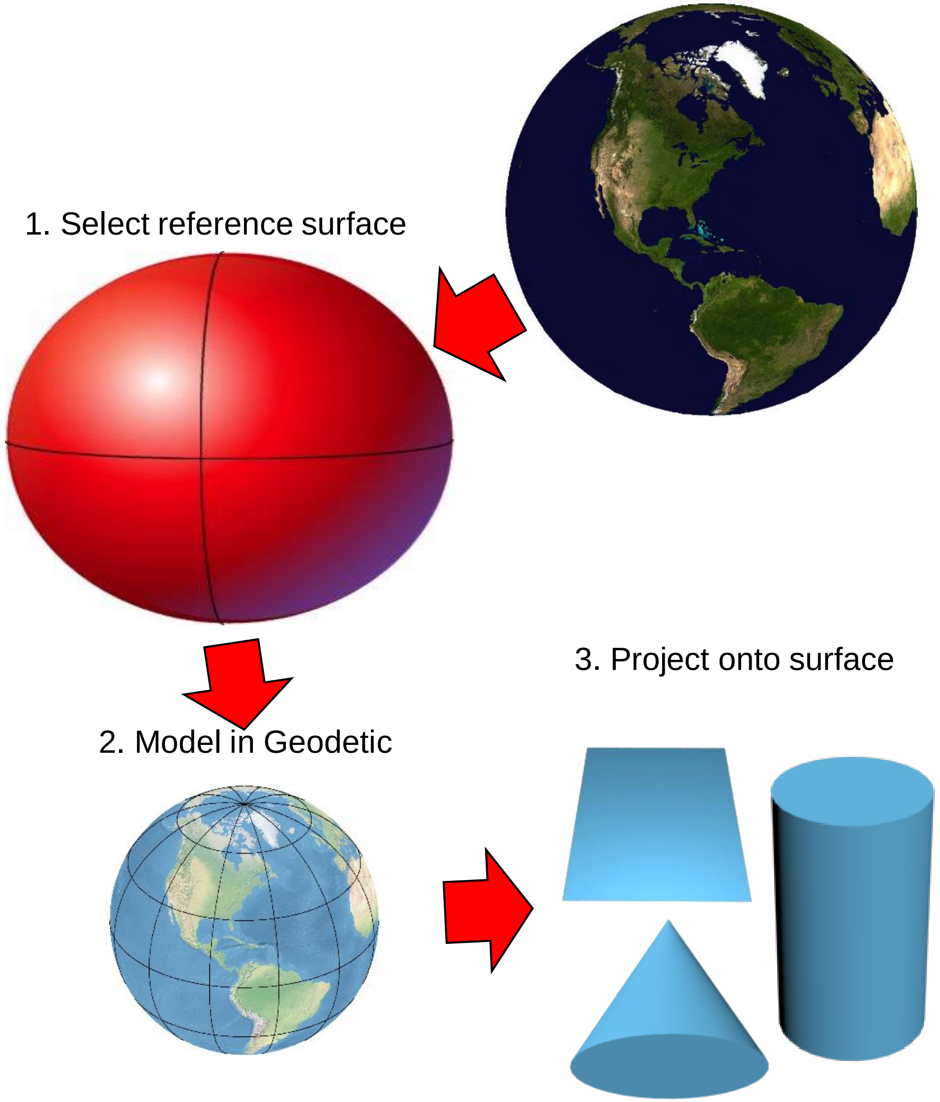
BLUE MARBLE GEOGRAPHICS

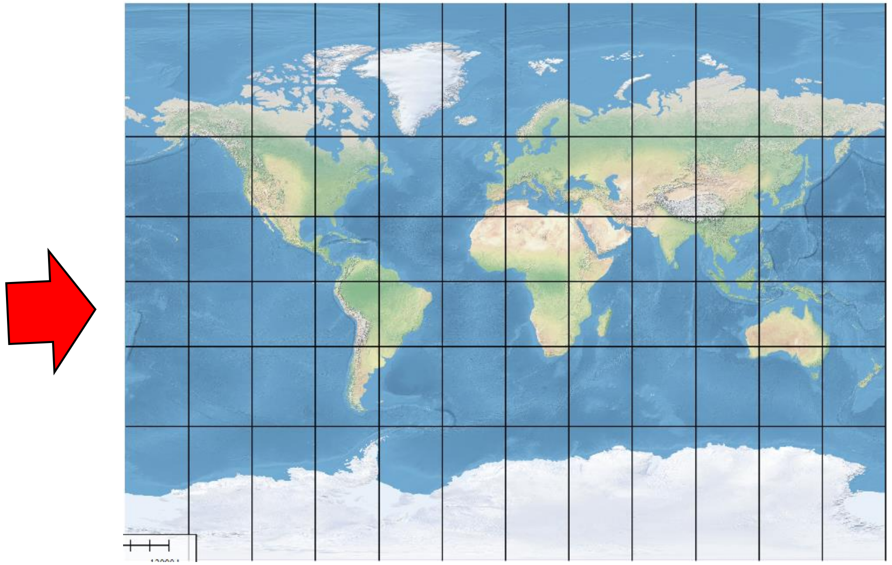
Map Projections

Round Earth, Flat paper:

- Projecting a coordinate system simply means taking an image of the Earth (3D) and accurately displaying it on a two-dimensional surface.

- Different projection methods will result in different geometric properties on the final map.

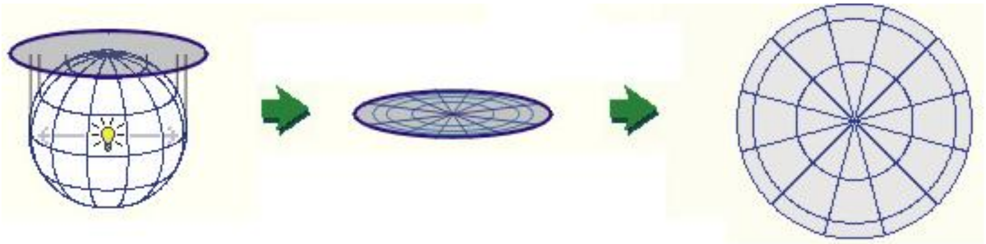




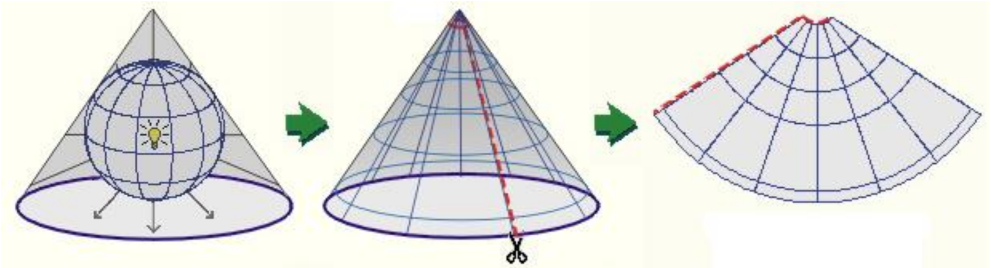
BLUE MARBLE GEOGRAPHICS

Projection Types

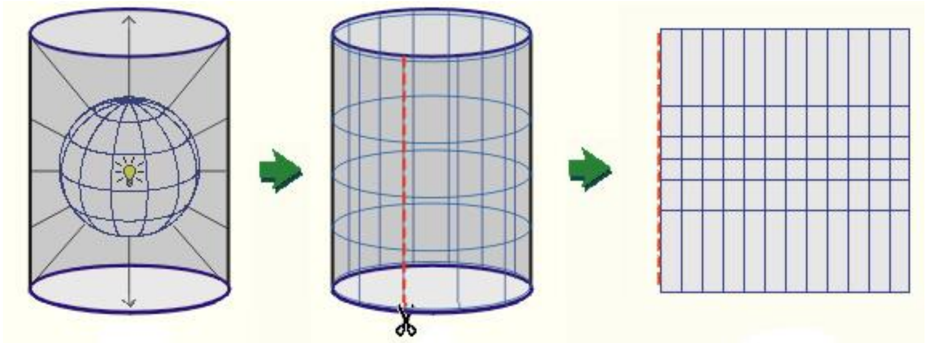
- ***Azimuthal***
  - The plane of projection touches the surface of the Earth at one point.



- ***Conic***
  - A cone shape is either tangent or secant to the globe, and the map is projected inside the cone.



- ***Cylindrical***
  - A cylinder is wrapped around the surface of the globe. The point of contact is a Great Circle.



BLUE MARBLE GEOGRAPHICS

Projection Properties

- **Equal Area**- Proportional preservation of surface areas. Linear and distance distortion occurs.

- **Equidistant**- Distances from the *center point* of the projection to any point (Great Circles) are preserved.

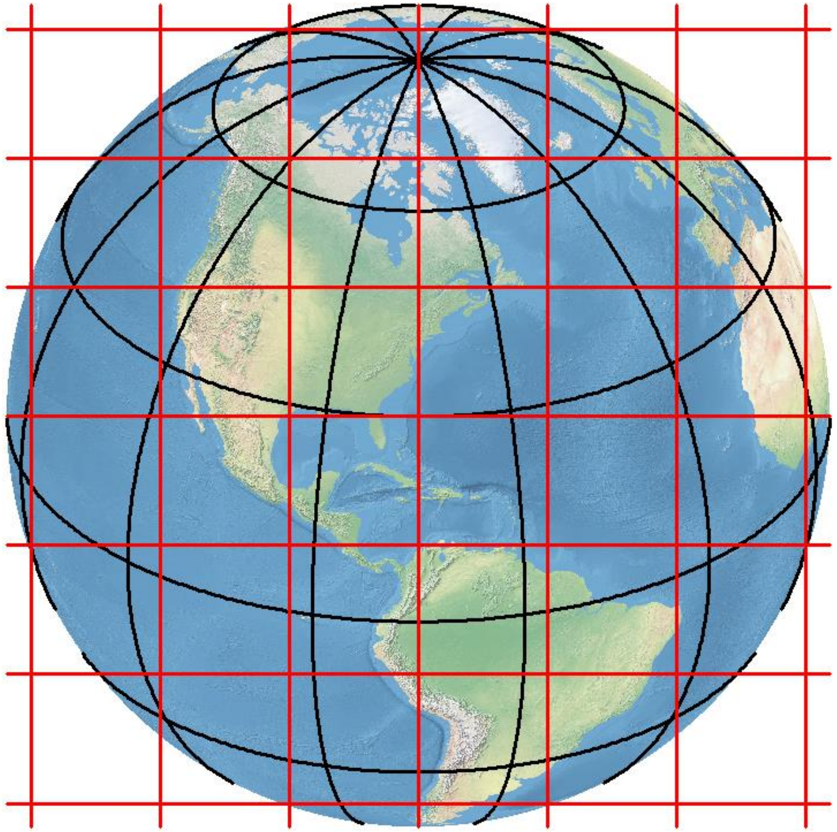
- **True Direction**- Rhumb lines represent true north azimuths. There is no convergence distortion.

- **Conformal**- Angles between points and shapes of small areas are preserved. The backbone of surveying coordinate systems.

BLUE MARBLE GEOGRAPHICS

Projection Terms (cont'd)

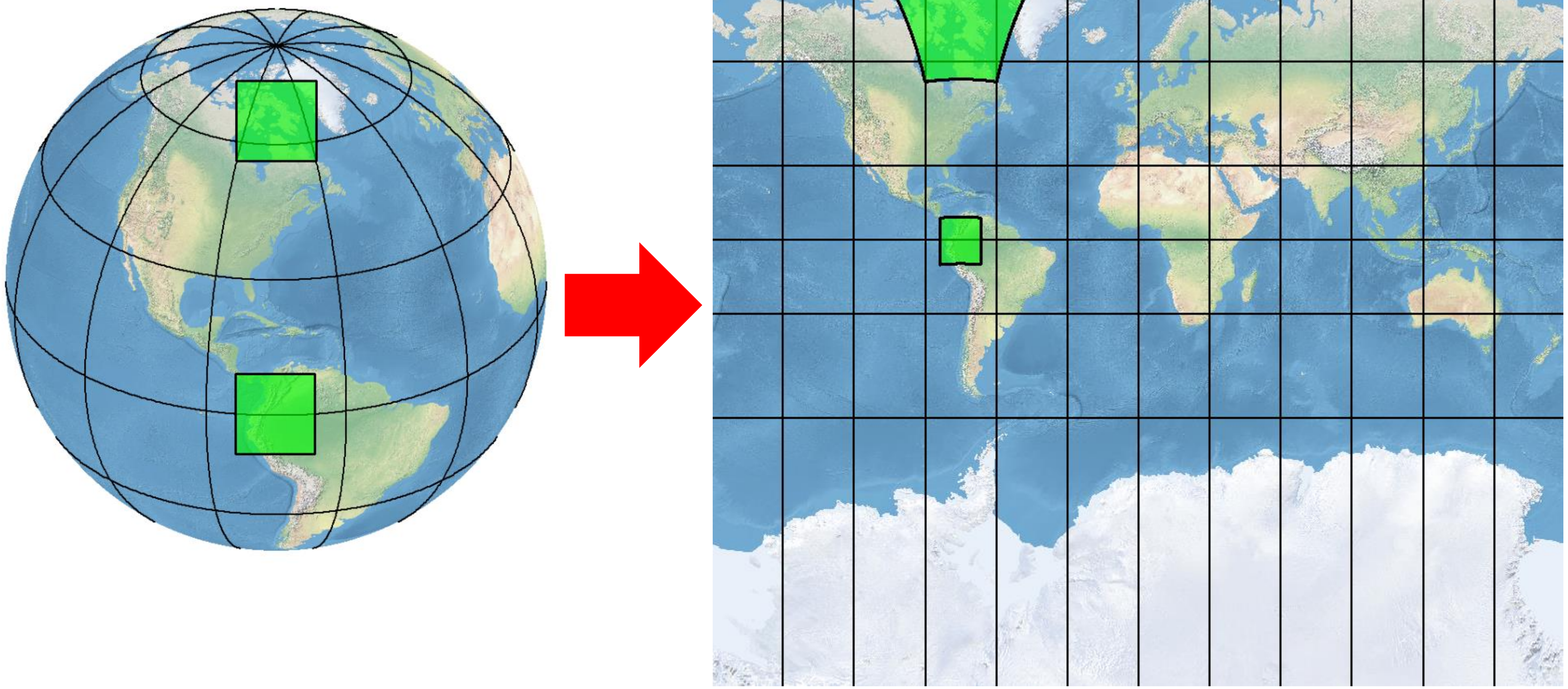
- **Convergence**
  - The horizontal angle at a point between true North and Grid North.



Projection Terms (cont'd)

Scale Factor

- The relationship between distance measured on the projected surface and distance measured on the ellipsoid.



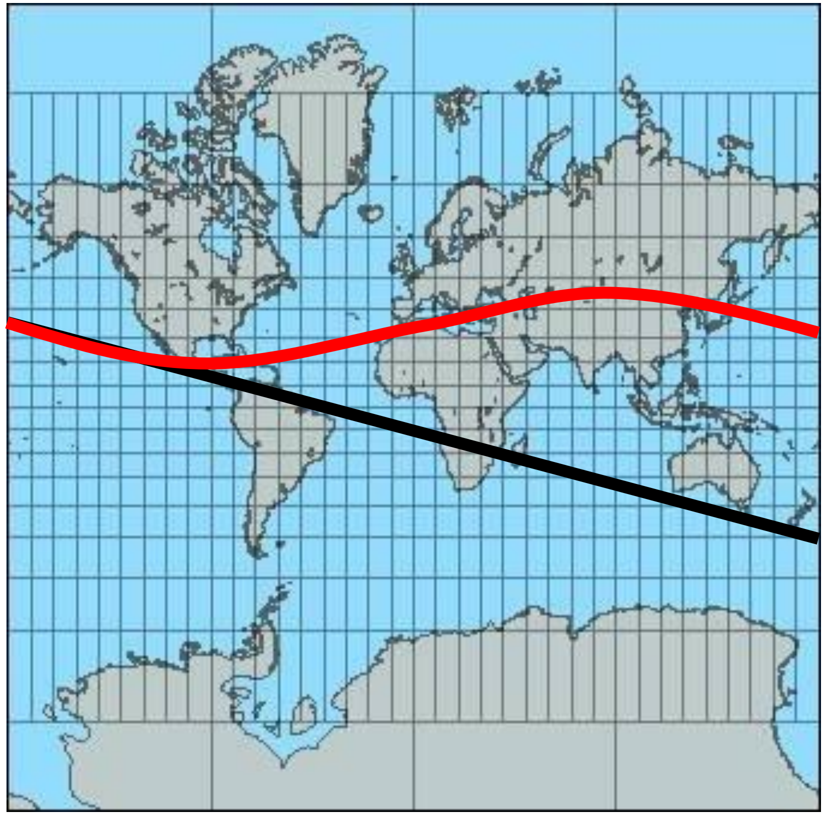
BLUE MARBLE GEOGRAPHICS

Projection Terms

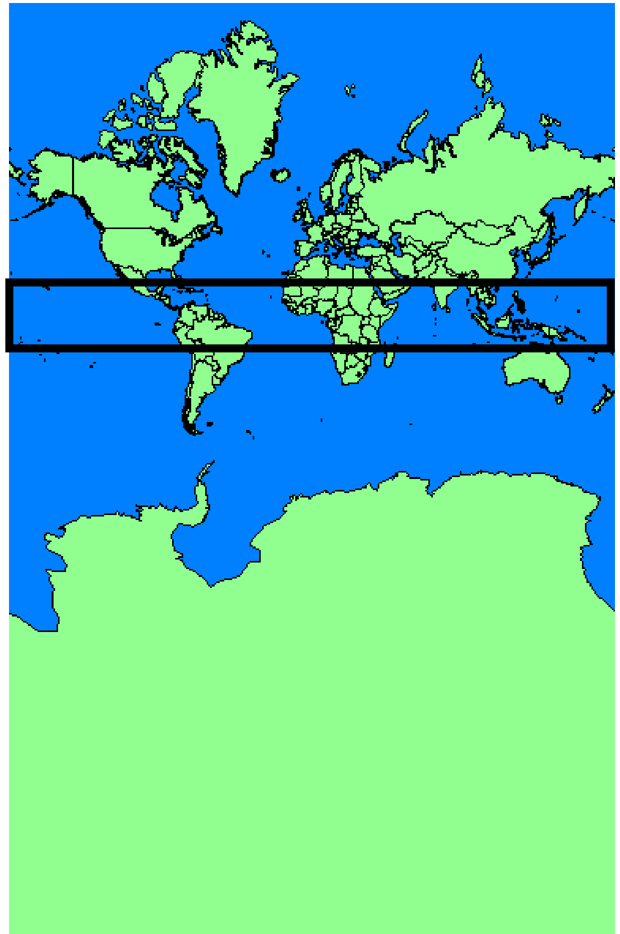
- **Azimuth**- Angle between North and direction of travel, measured clockwise from North.
  - Also called: Heading, Bearing, or Direction

- **Great Circle**- An arc that divides a sphere (in this case Earth) into two equal parts. Any line of Longitude (meridian) is a Great Circle.

- **Rhumb Line**- A line that intersects each meridian at the same angle.
  - Great for navigation



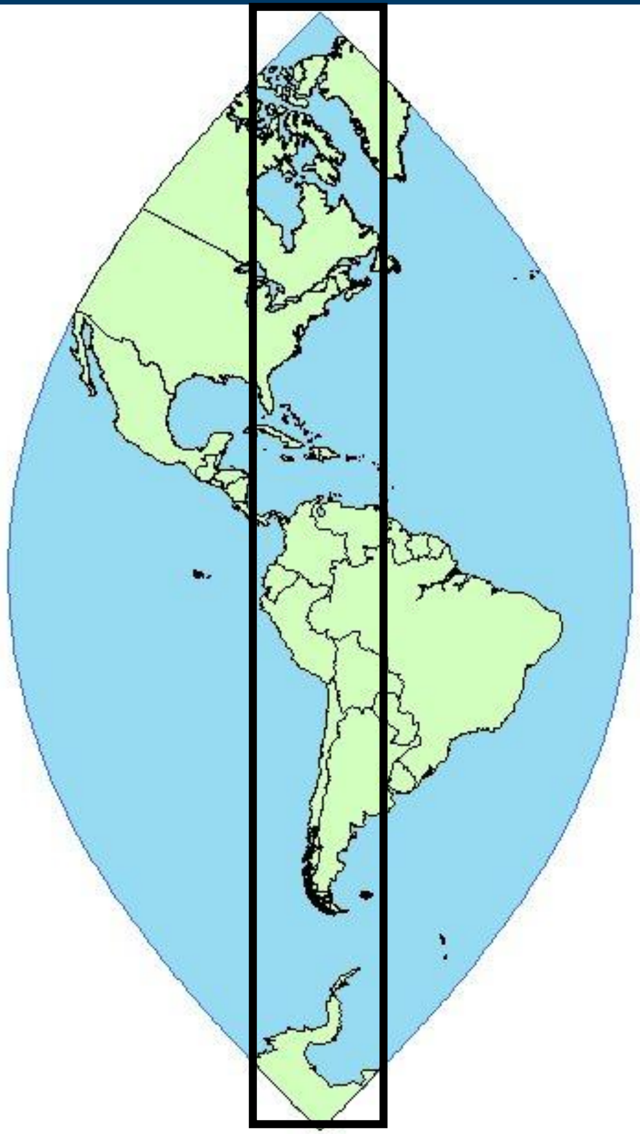
Mercator Projection



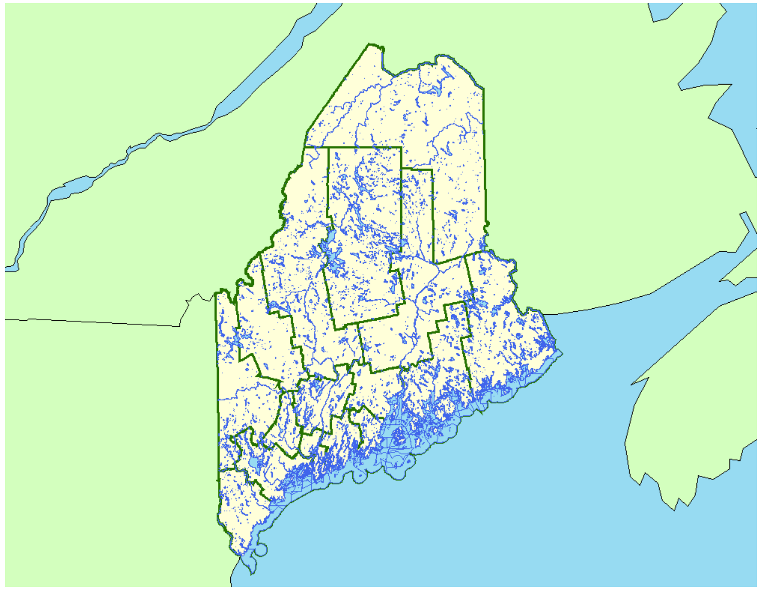
- Originally used for navigation.
- All meridians appear as parallel lines.
- Distances are true only along the Equator (or the parallel of origin), but are reasonably correct within 15° of the Equator
- Distortion increases further from the Equator and is extreme in polar regions.

BLUE MARBLE GEOGRAPHICS

Transverse Mercator

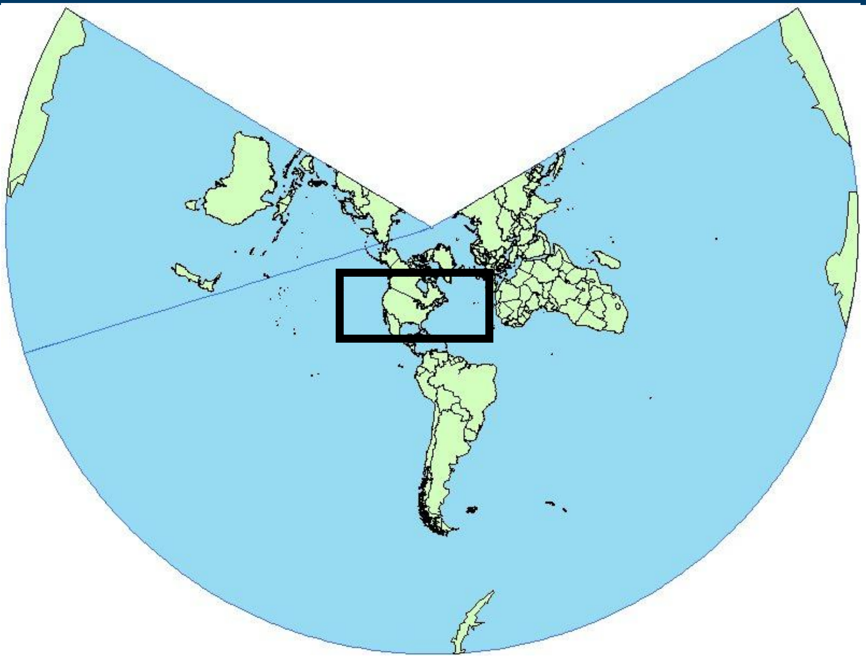


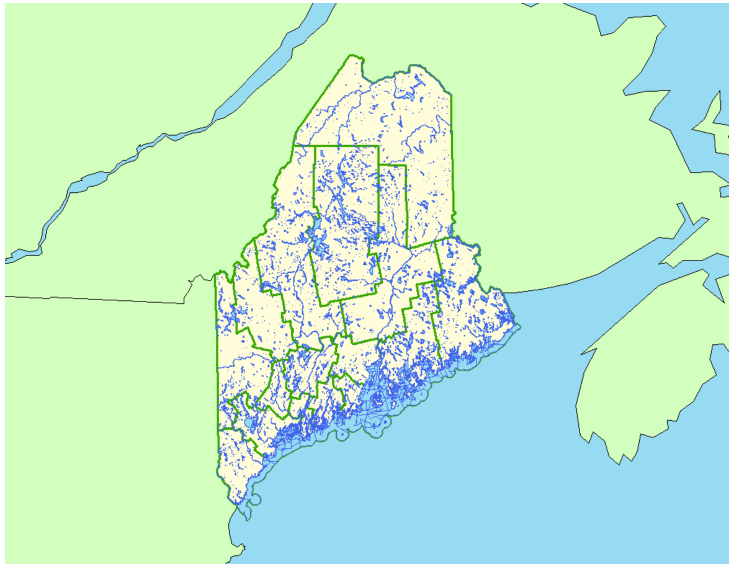
- Maps in this projection are used for mapping large areas that are mainly north-south in extent.
- Distances are true only along the central meridian, or two standard meridians.
- Used for most national grids, and of course Universal Transverse Mercator systems.



BLUE MARBLE GEOGRAPHICS

Lambert Conformal Conic



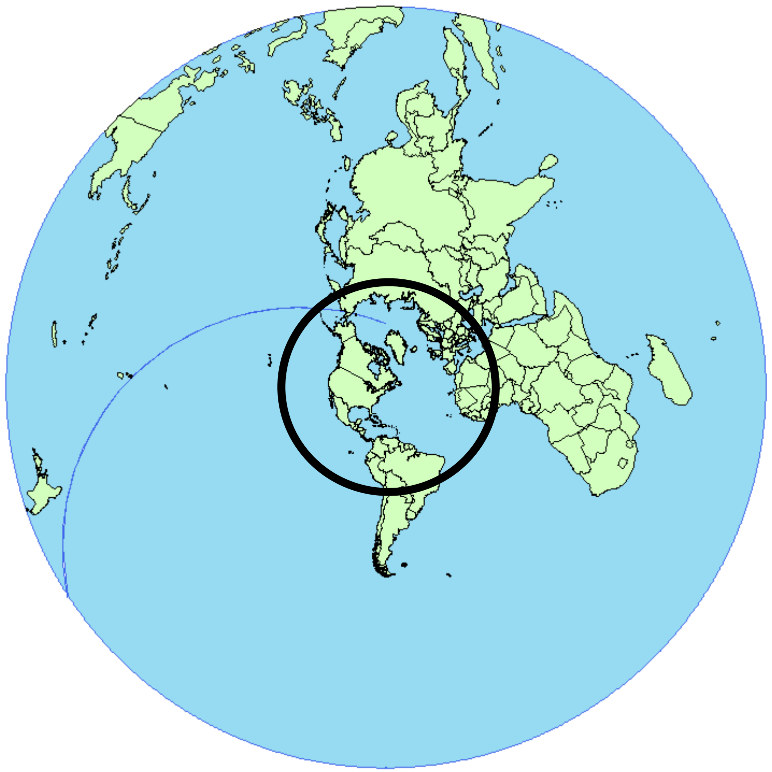


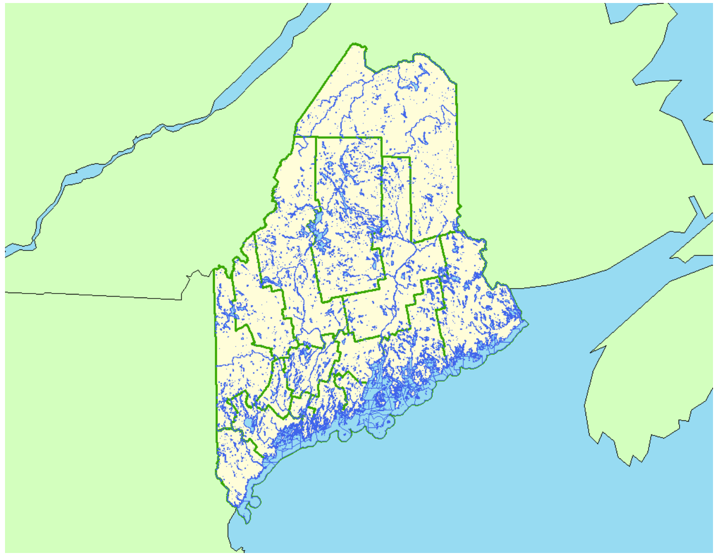
- Used to show a region that has a greater East-West extent in middle latitudes

- Distances are true only along the two standard parallels (lines of contact) and are reasonably accurate elsewhere in limited regions.

- Distortion of shapes and areas is minimal at, but increases away from standard parallels.

Stereographic





•Used to map large continent-sized areas of similar extent in all directions.

• Polar aspects are used for topographic maps and charts for navigating in latitudes above 80°.

•Scale increases away from the center point.

• Any straight line through the center point is a great circle. Distortion of areas and large shapes increases away from center point.

BLUE MARBLE GEOGRAPHICS

So Many Projections: How Do I Choose?

- Geographic Extent (area in which you want to map)

- What are you going to do with the map?
  - Properties of the projection

- What standards are already in place?
  - National grids, EPSG, business rules…

BLUE MARBLE GEOGRAPHICS

Further Reference

- NGS Video Library:
  http://www.ngs.noaa.gov/corbin/class_description/NGS_Video_Library.shtml
- Book: Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time by Dava Sobel
- Book: Datums and Map Projections: For Remote Sensing, GIS and Surveying, Second Edition *2nd Edition* by Jonathan Iliffe (Editor), Roger Lott (Editor)
- Book: Flattening the Earth: Two Thousand Years of Map Projections by John P Snyder

BLUE MARBLE GEOGRAPHICS

Thanks!
Questions, Discussion?

Sam Knight
Director of Product Management
geohelp@bluemarblegeo.com
www.bluemarblegeo.com