VIEPS GIS Course

Room 204
(Behind the lifts on level 2)

VIEPS GIS Shortcourse

Lecture 2: Projections and coordinate systems

Coordinate systems

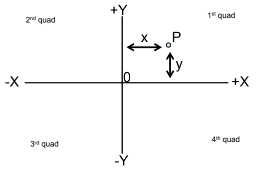
- Geographic coordinate systems
  - A map is a real world location defined in a mathematical coordinate space
  - Coordinates fix that point in space with given dimensions
    - 2D Map – x,y
    - 3D Map – x,y,z
    - Melways – E3

Coordinate systems

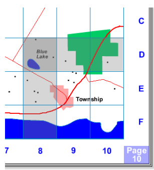
- There are 3 main coordinate systems
  - Plane rectangular
  - Plane polar
  - Geographic
- Coordinates are used because they
  - Standardise data collection
  - Allow coordinate transformations

Coordinate systems

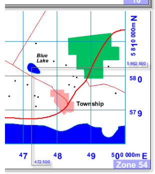
- Plane rectangular
  - Cartesian coordinates
  - Very simple system
  - Based on to lines intersecting at right angles
    - axes



Coordinate systems



Using our street directory coordinate system ***Blue Lake*** is located by the reference **Page 10, D8**.

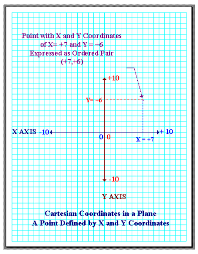


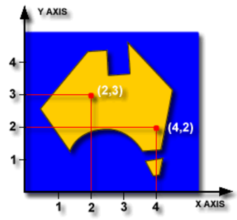
Using the Australian Map Grid (AMG) coordinate system the ***Blue Lake*** is located by the reference **472 500E, 5 802 500N**.

This system allows features to be located more exactly by interpolating coordinate values in both directions

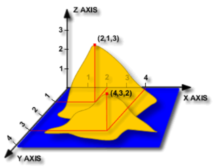
UTM Zones

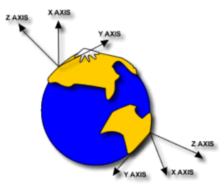
Cartesian coordinates





Coordinate systems



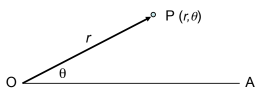


Cartesian Coordinate Systems in Australia

- Map Grid of Australia 1994 (MGA94)
- Phasing out Australian Map Grid
  - 1966
  - 1984.
- MGA and AMG coordinates are derived from the position's longitude and latitude
- Longitude and latitude are known as Geographic Coordinates.

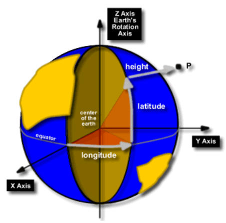
Coordinate systems

- Plane polar
  - Angular measurement and a plane measurement about a polar axis to fix location
  - Define
    - Radius vector – OP
    - Vectorial angle – θ (positive is clockwise)

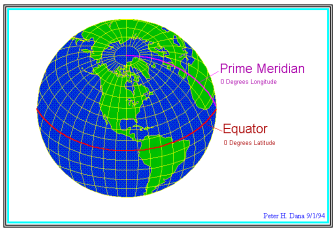


Coordinate systems

- Geographic coordinates
  - Longitude and latitude
    - Longitude intersect the poles
    - Numbered in degrees
    - Start at Royal Greenwich Observatory in England
    - latitude is measured as an angle from the equator (0°) to either Pole, 90° South and 90° North
    - the equator is a line of latitude



Coordinate systems



Meridians = Longitude

Parallels = Latitude

Prime Meridian = 0° Longitude

Equator = 0° Latitude

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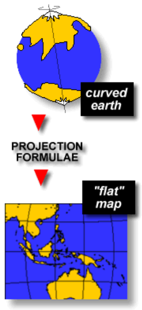
Projections

- We know the earth is not flat so how do we make a flat map of it?
  - Globe?
  - Squashed Globe?
    - => projections
- Projection formulae take the geographic coordinates from the spherical earth (longitude and latitude) and convert them to cartesian coordinates (X & Y).



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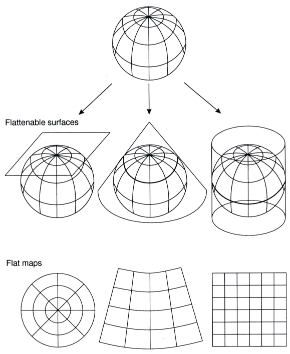

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- All map projections introduce distortions – your choice.
- Conformality
  - scale of a map at any point on the map is the same in any direction
  - meridians and parallels intersect at right angles
- Distance
  - distances from the center of the projection to any other place on the map
- Direction
  - azimuths (angles from a point on a line to another point) are portrayed correctly in all directions.
- Scale
  - Scale is maintained anywhere on the map
- Area
  - areas have the same proportional relationship to the areas on the Earth that they represent

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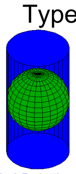
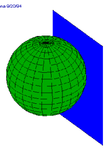
Types of projections



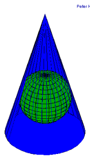
Cylindrical Projection Surface

Cylindrical projections result from projecting a spherical surface onto a cylinder

Azimuthal projections result from projecting a spherical surface onto a plane



Planar Projection Surface



Conical Projection Surface

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

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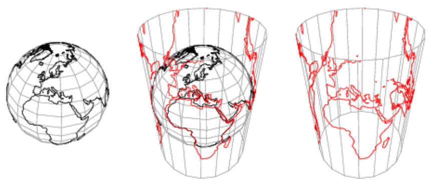
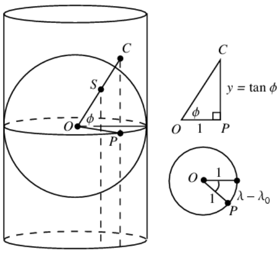
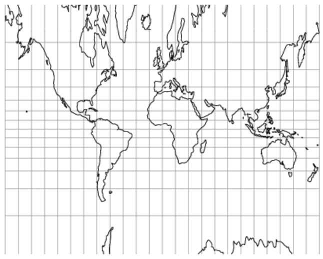






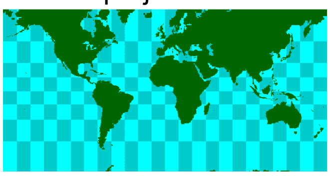
Projection properties

Projected grid of graticule	Scale		Properties			
	Parallel	Meridian	Area	Shape	Distance	Direction
(a)	Correct	Correct	Preserved	Preserved	Preserved	Preserved
(b)	Correct	Doubled	Distorted	Distorted	Preserved N–S only	Preserved only along parallels and meridians
(c)	Doubled	Correct	Distorted	Distorted	Preserved E–W only	Preserved only along parallels and meridians
(d)	Doubled	Doubled	Distorted	Preserved	Distorted	Preserved
(e)	Halved	Doubled	Preserved	Distorted	Distorted	Preserved only along parallels and meridians
(f) v	Correct; correct vertical interval (v)	Distorted	Preserved	Distorted	Preserved E–W; slightly distorted N–S	Preserved only along parallels

Common Map Projections, Their Properties and Major Uses

Projection/Construction	*Appearance*	*Properties*	*Major Uses*
Albers equal-area/conical	(a)	Equal area; conformal along standard parallels	Small regional and national maps
Azimuth equidistant/planar	(b)	Equidistant; true directions from map center	Air and sea navigation charts; equatorial and polar area large-scale maps
Equidistant conic/conical	(c)	Equidistant along standard parallel and central meridian	Region mapping of midlatitude areas with east–west extent; atlas maps for small countries
Lambert conformal conic/conical	(d)	Conformal; true local directions	Navigation charts; U.S. State Plan Coordinate System (SPCS) for all east–west State Plane Zones; continental U.S. maps; Canadian maps
Mercator/cylindrical	(e)	Conformal; true direction	Navigation charts; conformal world maps
Polyconic/conical	(f)	Equidistant along each standard parallel and central meridian	Topographic maps; USGS 7.5- and 15-min quadrangles
Robinson/pseudocylindrical	(g)	Compromise between properties	Thematic world maps
Sinusoidal/pseudocylindrical	(h)	Equal area; local directions correct along central meridian and equator	World maps and continental maps
Stereographic/planar	(i)	Conformal; true directions from map center	Navigation charts; polar region maps
Transverse Mercator/cylindrical	(j)	Conformal; true local directions	Topographic mapping for areas with north–south extent; U.S. State Plan Coordinate System (SPCS) for all north–south State Plane Zones

Mercator projections

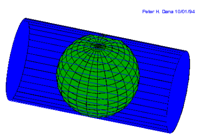


The Mercator projection has straight meridians and parallels that intersect at right angles

Scale is true at the equator or at two standard parallels equidistant from the equator

The projection is often used for marine navigation because all straight lines on the map are lines of constant azimuth.

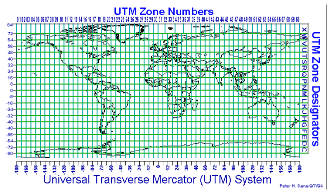
Transverse Mercator



Transverse Cylindrical Projection Surface

- projecting the sphere onto a cylinder tangent to a central meridian
- used to portray areas with larger north-south than east-west extent
- distortion of scale, distance, direction and area increase away from the central meridian
- many national grid systems are based on the Transverse Mercator projection

UTM – Universal Transverse



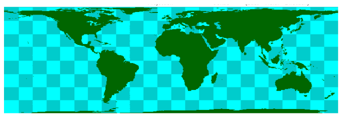
• Defines horizontal, positions by dividing the surface of the Earth into 6 degree zones

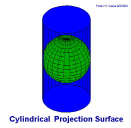
• Each mapped by the Transverse Mercator projection with a central meridian in the center of the zone

• UTM zone numbers designate 6 degree longitudinal strips extending from 80 degrees South latitude to 84 degrees North latitude

• UTM zone characters designate 8 degree zones extending north and south from the equator

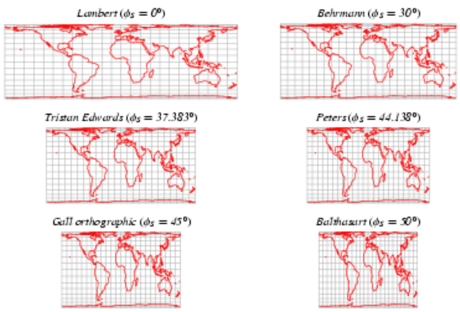
Cylindrical Equal Area



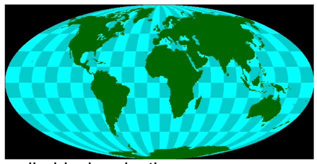


• straight meridians and parallels
  •meridians are equally spaced
  •parallels unequally spaced.
• normal, transverse, and oblique
• scale is true along the central line (equator) and along two lines equidistant from the central line.
• shape and scale distortions increase near points 90 degrees from the central line

Equal Area

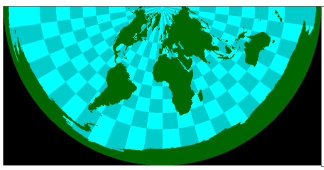


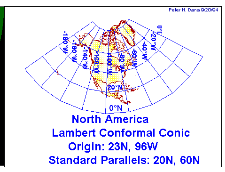
Pseudocylindrical projections



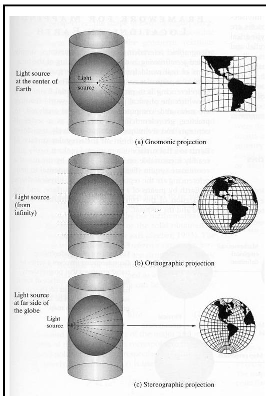
- resemble cylindrical projections
  – straight and parallel latitude lines and equally spaced meridians
  – other meridians are curves
- The Mollweide projection, used for world maps, is pseudocylindrical and equal-area
  – The central meridian is straight.
  – The 90th meridians are circular arcs.
  – Parallels are straight, but unequally spaced.
  – Scale is true only along the standard parallels of 40:44 N and 40:44 S.

Conic projections

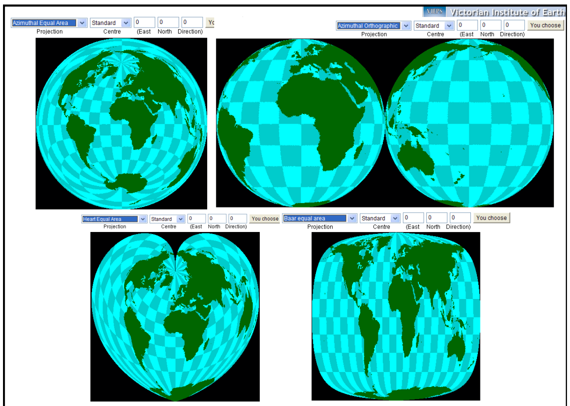




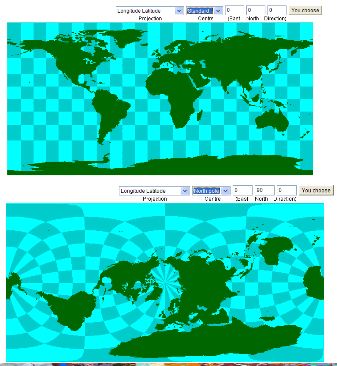
- Albers Equal Area Conic
  – distorts scale and distance except along standard parallels
  – used in large countries with a larger east-west than north-south extent
- Equidistant Conic
  – direction, area, and shape are distorted away from standard parallels
  – used for portrayals of areas near to, but on one side of, the equator
- Lambert Conformal Conic
  – area, and shape are distorted away from standard parallels
  – directions are true in limited areas. Used for maps of North America

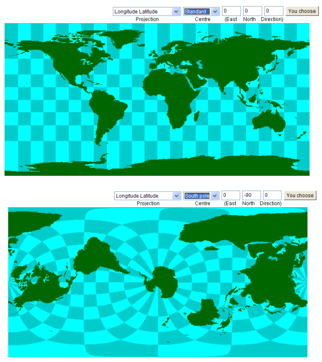


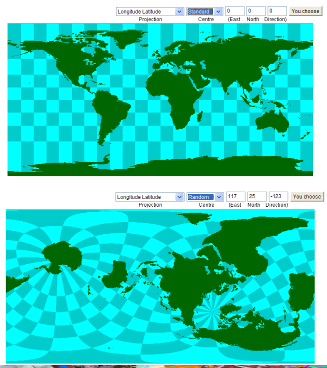
- Projection points
  – Gnomonic
    • Great circles are straight
    • Navigation
  – Orthographic
    • Similar to space view
    • Preserve area locally
  – Stereographic
    • Lat and long curved
    • Angle 90 deg
    • Shape preserved
    • Compromise projection



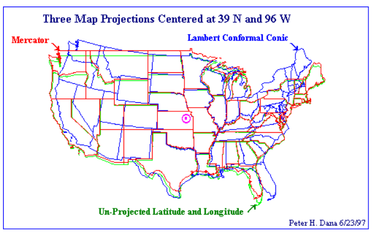
http://www.btinternet.com/~se16/js/mapproj.htm





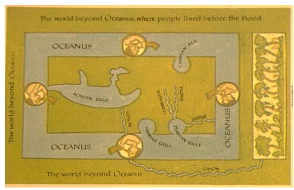


Why is this important?



The shape of the earth

Homer 900BC

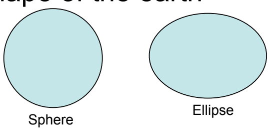


Cosmas Indicopleustes 600AD

Medieval view

Other historical ideas included:
- oyster (The Babylonians before 3000 B.C.)
- a rectangular box
- a circular disk
- a cylindrical column
- a spherical ball
- a very round pear (Columbus).

The shape of the earth



- Spherical Earth
  - Sixth century BC – Pythagoras, Aristotle, Euclid, and Aristarchus, Ptolemy (first c. AD)
  - Aryabhatta and Brahmagupta
- 1600's Issac Newton proposed an elliptical model for the Earth
- the earth's surface is actually very complex, its shape is simplified so that distances can be calculated mathematically
- for most practical purposes, estimating the shape of the earth using a sphere is accurate enough over relatively short distances
- modelling the shape of the earth as accurately as possible is vital for geodesists who make very precise calcuations on its surface over long distances

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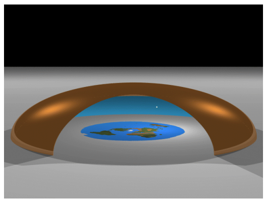
… or is it?



According to Charles K. Johnson, president of the International Flat Earth Research Society, "One thing we know for sure about this world...the known inhabited world is Flat, Level, a Plain World. … The Fact the Earth is Flat is not my opinion, it is a Proved Fact. Also demonstrated Sun and Moon are about 3,000 miles away are both 32 miles across. The Planets are 'tiny.' Sun and Moon do Move, earth does NOT move, whirl, spin or gyrate." Johnson continues, "You can't orbit a flat earth. The Space Shuttle is a joke--and a very ludicrous joke."

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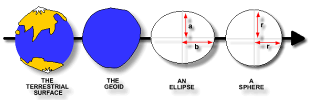
Life would be easier if it was flat.



- The **terrestrial** (topographic) surface refers to the earth's topography. It is very complex with mountain ranges and oceans
  - Used by pilots/navigators (luckily).

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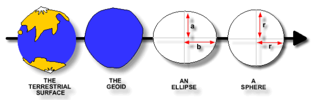

- The **geoid** estimates the earth's surface using mean sea level of the ocean with all continents removed
  - Due to variations in the earth's mass distribution (oceans and land), the Geoid has an irregular shape that is described as "undulating".
  - It is an *equipotential* surface. This means that potential gravity is the same at every point on its surface.

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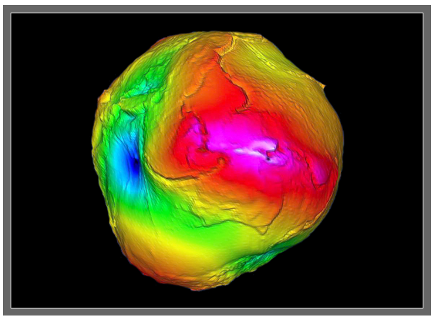

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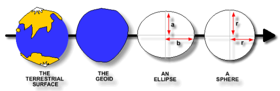
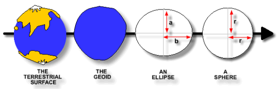
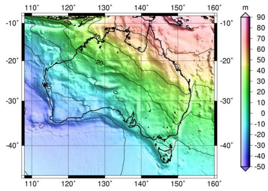


- The flattening of the earth as it spins produces a shape that is mathematically defined as an **ellipsoid of revolution**
  - It is a mathematical approximation of the Geoid. This shape is used for exact measurements over long distances, across continents or oceans.
  - Choose the ellipsoid that best fits the area of interest



- The ellipsoid can be further simplified into a **sphere**. To define a sphere, only the radius is required. The radius often used when modeling the earth as a sphere is 6371 000 meters.

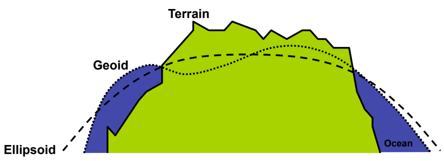
Geoid again (because it confuses the hell out of me sometimes)



- Sea level is the average surface of the oceans. Tidal forces and gravity differences from location to location cause even this smoothed surface to vary over the globe by hundreds of meters.

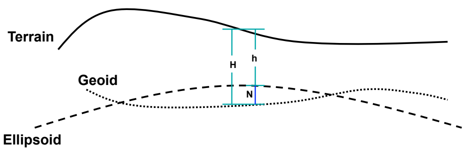
- Gravity models attempt to describe in detail the variations in the gravity field.
  - ie. the direction perpendicular to a plumb bob pointing toward the center of mass of the earth.
  - Local variations in gravity, caused by variations in the earth's core and surface materials, cause this gravity surface to be irregular.

- Geoid models attempt to represent the surface of the entire earth over both land and ocean as though the surface resulted from gravity alone.
  - ie. the surface that would exist if the sea was admitted under the land portion of the earth by small frictionless channels.

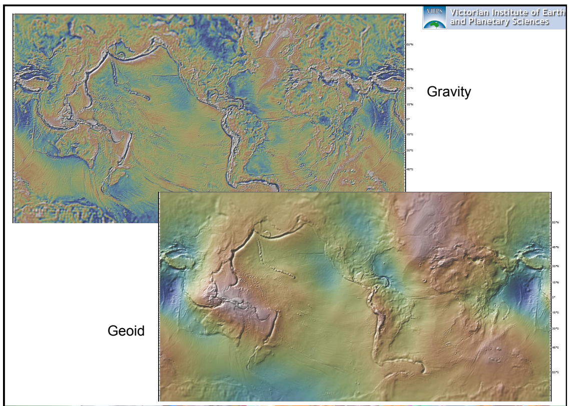


N.

The value N is the geoid-ellipsoid variation



Barrometric heights are measured from the geoid
GPS heights are measured from the ellipsoid

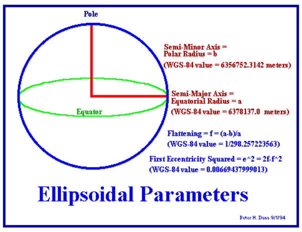


Gravity

Geoid

Minute physics

http://www.youtube.com/watch?v=q65O3qA0-n4



- Reference ellipsoids are usually defined by semi-major (equatorial radius) and flattening (the relationship between equatorial and polar radii).
- Other reference ellipsoid parameters such as semi-minor axis (polar radius) and eccentricity can computed from these terms.

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Ellipsoids cont.

Selected Reference Ellipsoids

Ellipse	Semi-Major Axis (meters)	1/Flattening
Airy 1830	6377563.396	299.3249646
Bessel 1841	6377397.155	299.1528128
Clarke 1866	6378206.4	294.9786982
Clarke 1880	6378249.145	293.465
Everest 1830	6377276.345	300.8017
Fischer 1960 (Mercury)	6378166.0	298.3
Fischer 1968	6378150.0	298.3
G R S 1967	6378160.0	298.247167427
G R S 1975	6378140.0	298.257
G R S 1980	6378137.0	298.257222101
Hough 1956	6378270.0	297.0
International	6378388.0	297.0
Krassovsky 1940	6378245.0	298.3
South American 1969	6378160.0	298.25
WGS 60	6378165.0	298.3
WGS 66	6378145.0	298.25
WGS 72	6378135.0	298.26
WGS 84	6378137.0	298.257223563

Peter H. Dana 9/1/94

Semi-major axis (a) and Flattening (1/F) values for several commonly used ellipsoids

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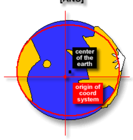
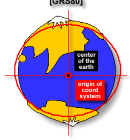
Ellipsoids in Australia

LOCAL GEODETIC DATUM [ANS]



GEOCENTRIC DATUM [GRS80]



- The Australian Map Grid [AMG66/84] was based on the Australian National Spheroid [ANS]
  - ellipsoid designed to be the best estimate of the earth's shape around the Australian continent
  - the origin of the ellipsoid used in its definition did not correspond with the centre of the earth
  - all coordinates will shift by approximately 200m to the north
- The Map Grid of Australia MGA94 uses the GRS80 ellipsoid.
  - best estimate of the earth's shape globally
  - its centre corresponds with the centre of the earth.

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What is a Datum?

- A datum is a framework that enables us to define coordinate systems.
- **Traditional Geodetic Datums - The AGD66/84**
  - To describe positions on the earth accurately, horizontal and vertical datums were required.
- **Vertical Datum**
  - A Vertical Datum is used to fix a position in the vertical direction, up and down the Z axis.
  - Australia's vertical datum is the Australian Height Datum [AHD] which approximates mean sea level
  - This was calculated by monitoring tide gauges around the Australian coastline.
- **Horizontal Datum**
  - A horizontal datum is used to fix a position in the X and Y directions.
  - The horizontal Datum was traditionally defined using an ellipsoid and an origin
  - The ellipsoid was generally chosen for a best fit of the geoid locally
  - The origin of the AGD66/84 is the Johnston Geodetic Station (NT)

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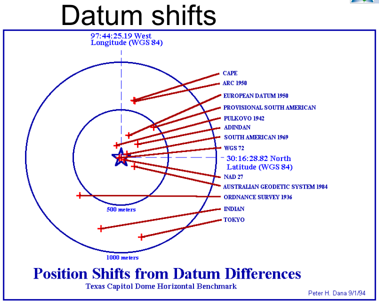
Datum shifts



Coordinate values resulting from interpreting latitude, longitude, and height values based on one datum as though they were based in another datum can cause position errors in three dimensions of up to one kilometer.

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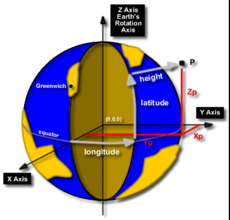
Modern Geodetic Datums

- The shape of the earth and location of points on it can now be measured much more accurately
  - reduces the need for locally derived datums
- Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR) and the Global Positioning Sytem (GPS)
- International Terrestrial Reference Frame (ITRF)
  - it is geocentric, the center of mass being defined for the whole Earth, including oceans and atmosphere.
  - the unit of length is the meter (SI).
  - Incorporates conditions that allow for changes resulting from tectonic activity

Modern Geodetic Datums - GDA94

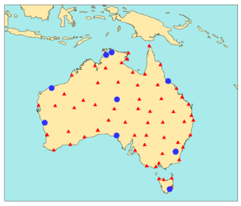
- New datums can now be based on several well determined points.
- GDA94 based on 8 points - Australian Fiducial Network [AFN]
- Part of the ITRF
- The measurements relate to a 3D earth-centered cartesian coordinate system
- This system could be considered a 'global' 3D cartesian coordinate system



AFN and ANN

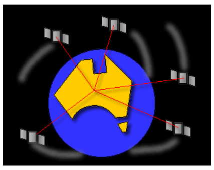
Australian Fiducial Network (AFN)

Australian National Network (ANN)

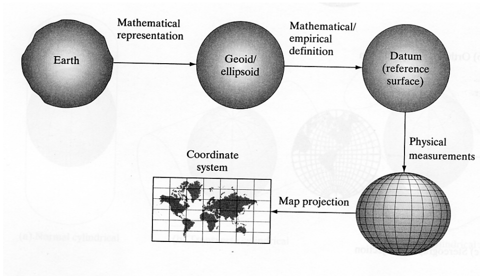


Why use a Geocentric Datum?

- GPS is based on a geocentric datum
- to use AGD66/84 coordinates you need to convert the GPS coordinates to that datum
  - Easy on the computer, harder in your head
- using GDA94, the datums will both be based on the same ellipsoid
  - Read the data straight from the GPS unit.



Georeferencing transformations



Summary

- Coordinate Systems
  - Division of map area into equal portions using an infinite combination of lines
  - Cartesian coordinates
  - Map Grid of Australia
- Projections
  - Projection formulae take the geographic coordinates from the spherical earth (longitude and latitude) and convert them to cartesian coordinates (X & Y).
  - Map projections introduce distortions

Summary

- Geiod
  - The geoid estimates the earth's surface using mean sea level of the ocean with all continents removed
- Ellipsoid
  - Mathematical approximation of the Geoid
  - Choose ellipsoid for best fit
- Datum
  - A set of parameters and control points used to accurately define the three-dimensional shape of the Earth. The corresponding datum is the basis for a planar coordinate system.

Too many choices!

- When creating digital maps or importing information into GIS datasets
  - Coordinate system
  - Projection
  - Geoid and/or ellipsoid
  - Datum
- If you use the wrong ones your data will be in the wrong place!