Datum and Projection Fundamentals for GIS

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A Fundamental Question

Where are we?

Our latitude/longitude is: 27°29′50″S 153°53′00″E .

Most professional mapping and GIS software doesn't work with degrees, minutes, seconds but with decimal degrees expressed as XY (Cartesian) coordinates.

So, how do we express this location in a way that can be entered into the software?

- That is, express this location (27°29′50″S 153°53′00″E) in decimal degrees to a precision of less than 1 metre

Answer

27°29′50″S 153°53′00″E = 153.883333 , -27.497222

Note:

1. insertion of sign to denote the Earth’s quadrant
2. reversal of order: latitude is an X value; longitude is a Y value
3. 6 decimal places gives a precision of about 10cm at the Equator

Distance precision at the equator:

decimal places	degrees	distance
0	1.0	111 km
1	0.1	11.1 km
2	0.01	1.11 km
3	0.001	111 m
4	0.0001	11.1 m
5	0.00001	1.11 m
6	0.000001	0.111 m
7	0.0000001	1.11 cm
8	0.00000001	1.11 mm

Some trick questions

1. Is the lat/long for a specific locality (e.g. 27°29′50″S 153°53′00″E) unique?
2. What would be the longitude reading on a GPS using the standard WGS84 datum placed on the Prime meridian line at Greenwich Observatory?
3. If an azimuth bearing taken at London along the great circle passing through Saint Petersburg was 060, would you expect the back-bearing from Saint Petersburg towards London to be 240?

Some trick answers

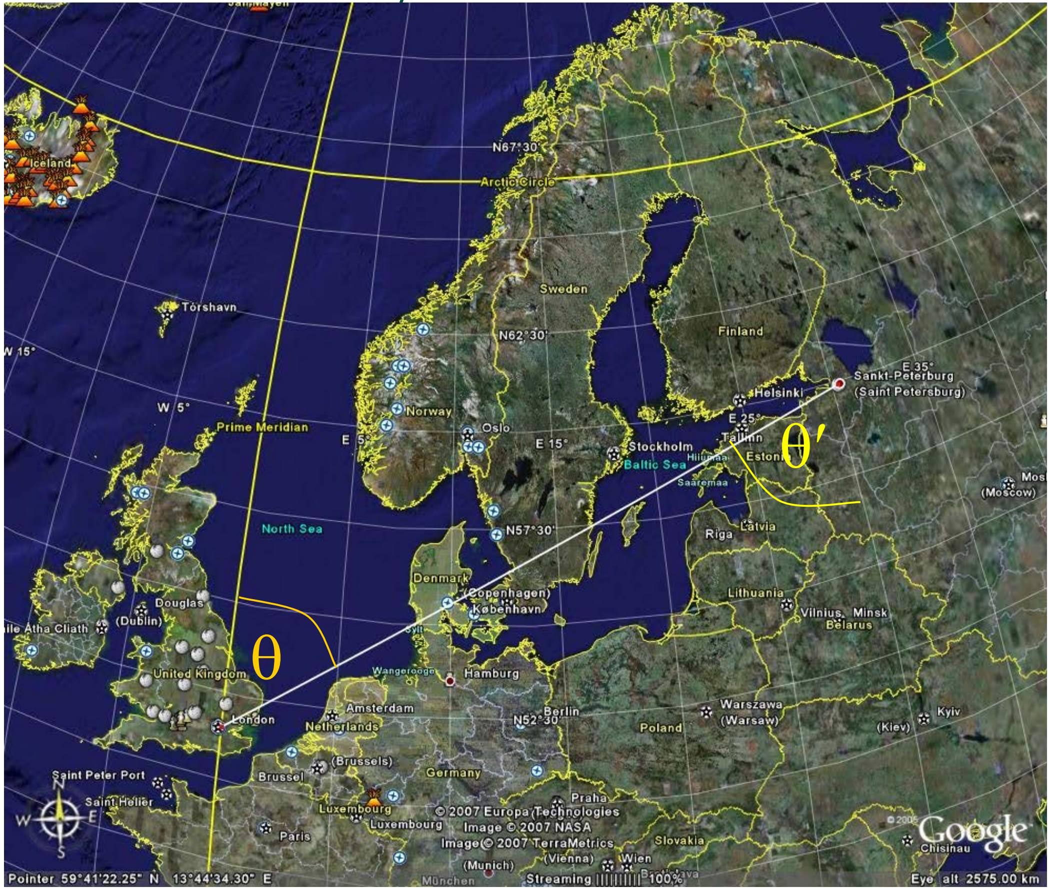
1. No. The latitude-longitude used to describe a point on the Earth's surface is dependent on the shape of the ellipsoid used to represent the Earth, the precise location of the ellipsoids centre relative to the Earth's centre, and on the elevation difference between the point and the ellipsoid. Thus we introduce the concept of a Datum – the shape and location of an ellipsoid used to represent the Earth's surface. More on this a little later.

2. The Prime Meridian defined at Greenwich By Sir George Airy has been the zero longitude for most historical nautical navigation. However, the WGS84 datum used in GPS instruments uses a zero meridian as defined by the Bureau International de l'Heure in Paris, based on a mean of compiled star observations from different countries. The WGS84 zero meridian is 102.5 metres east of the marked Prime Meridian at Greenwich Observatory.
3. No. Great circles that are highly oblique to the local longitude meridian intersect successive meridians at different angles (see next figure). North at any location is based on the local meridian, and azimuths are base on local North. Hence the local azimuth of the great circle changes, although it is only important over large distances.

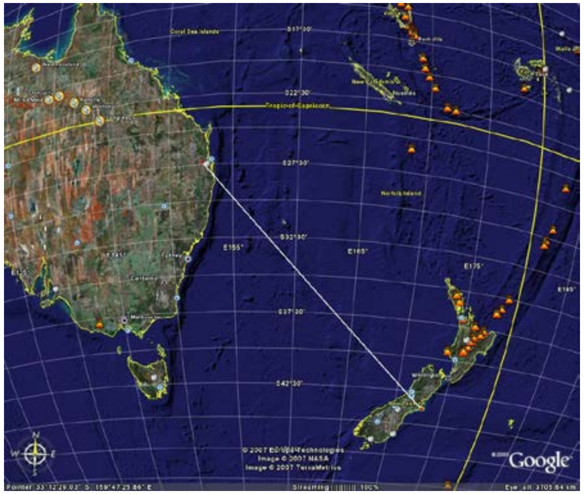
Forward bearings ≠ back bearings

Try reproducing the following diagrams in 3D on a globe using string

- Only critical in high latitudes or where extreme accuracy is required or for extremely long paths
  - For example, when capturing the orientation of lineaments from a satellite image for statistical analysis!

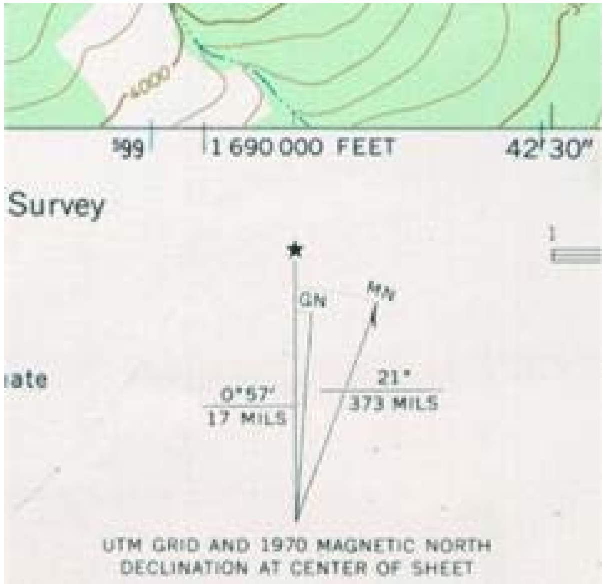


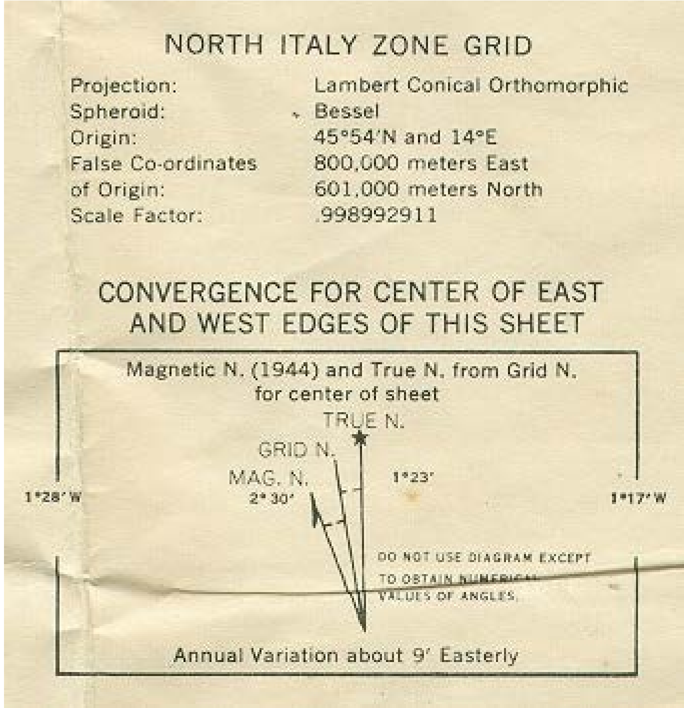
It raises the question:
What is North?



The Idea of North

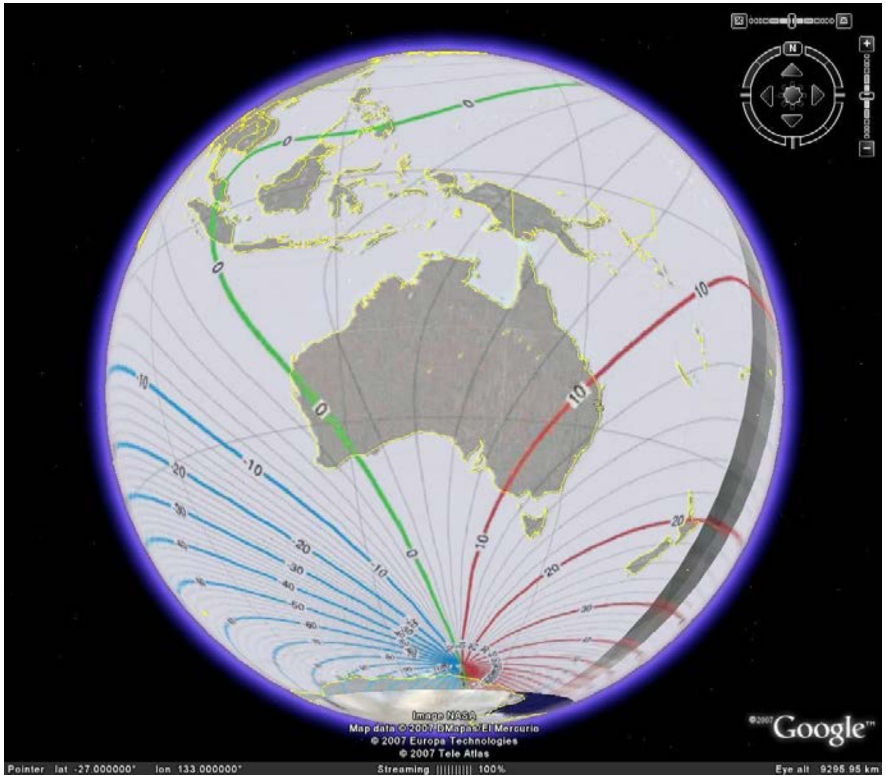
- True North
  - direction toward the E’s north pole
  - direction of a meridian of longitude at the point of observation for a particular spheroid model of the Earth
- Magnetic North
  - direction toward E’s magnetic pole
  - MN on a map is date dependent
- Grid North
  - direction northwards along the grid lines of a map projection
  - angle between GN & TN varies across a map sheet



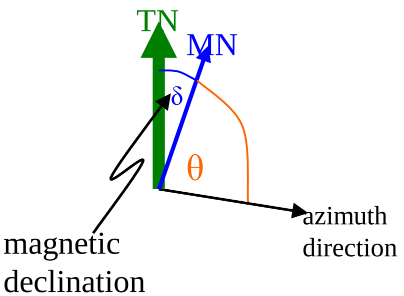


Magnetic declination

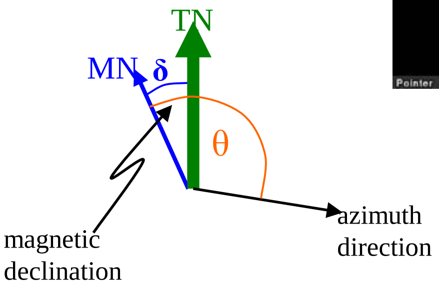
- East or West
- Changes with time



- Note whether directions are to TN or MN in any log, notebook, or table



TN = MN(θ) + δ

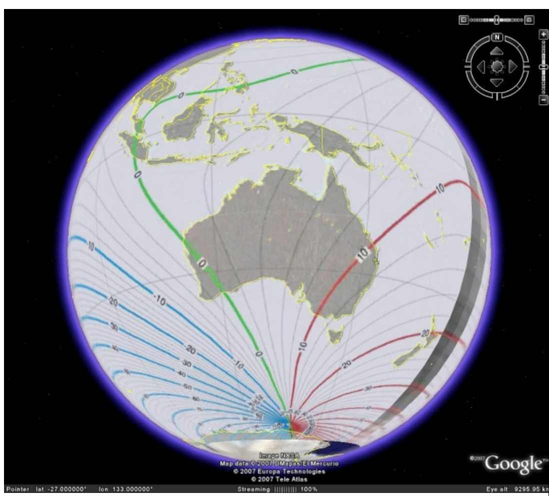


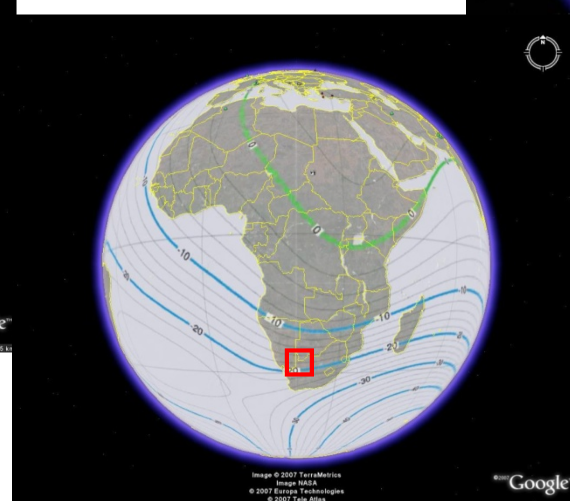
TN = MN(θ) - δ

Declination gradients

- Controls variations of MN across large area maps
- Not a problem in areas of low gradients
  - eg. Southeast Asia

- Is a particular problem at high and low latitudes
  - Russia
  - South Africa
  - Southern South America





Declination rate of change*

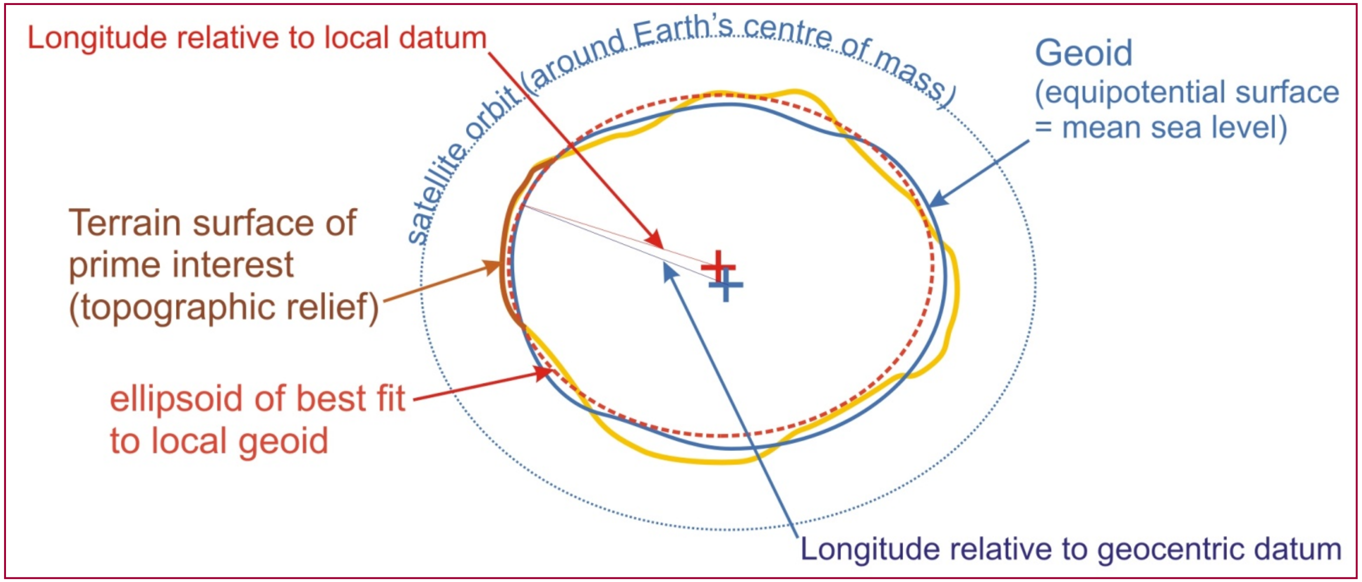
- **Montevideo**, Uruguay: **8° 48’ W** changing by **0° 8’ W/yr**
  - time to change by 1° = 8 years
- **Cape Town**, South Africa: **24° 29’ W** changing by **0° 7’ W/yr**
  - time to change by 1° = 9 years
- **Bamako**, Mali: **5° 16’ W** changing by **0° 6’ E/yr**
  - time to change by 1° = 12 years
- **Klaeng**, Thailand: **0° 35’ W** changing by **0° 3’ W/yr**
  - time to change by 1° = 20 years
- **Melbourne**, Australia: **11° 37’ E** changing by **0° 0’ E/yr**
  - the declination is constant into the near future (but the rate of change itself is not constant so it will change at some time in the future)

- **Note that during the 40+ year life of many mining districts the magnetic declination may change by more than 5 degrees!**
- Thus: Use TN where possible. Be particularly careful with directions used for drillhole orientations
- Record the declination, rate of change, **and the date** in any field book or field log

- *US National Geophysical Data Center) site (NGDC):
  - http://www.ngdc.noaa.gov/seg/geomag/jsp/struts/calcDeclination

Map Datums

Earth is neither a sphere nor a true ellipsoid



***Note: the latitude and longitude of a point on the earth depends on the datum used

WGS84-geoid

- WGS84-geoid (1996)
  - NB: Geoid definitions vary with time due to:
    - plate motions
    - increasing precision of the grid and measurements used to define it

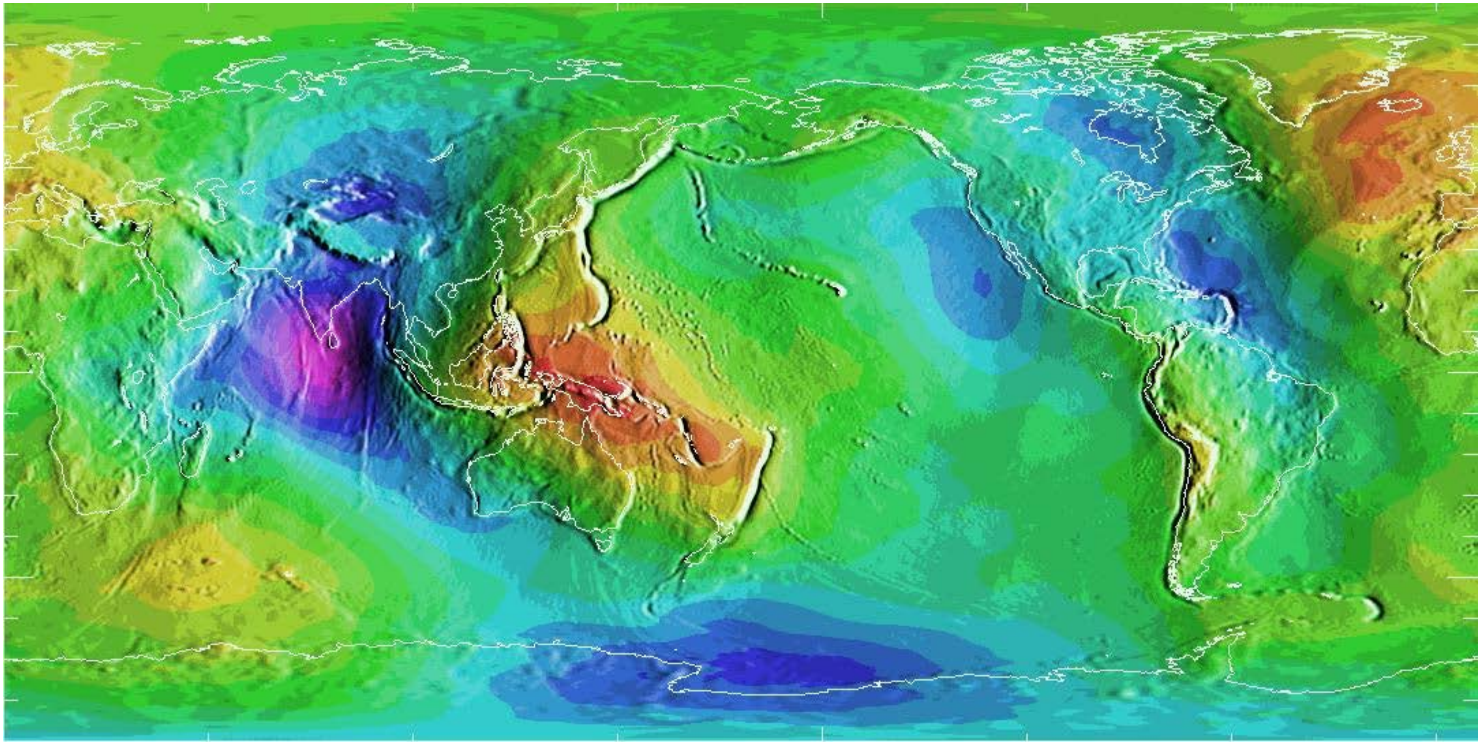
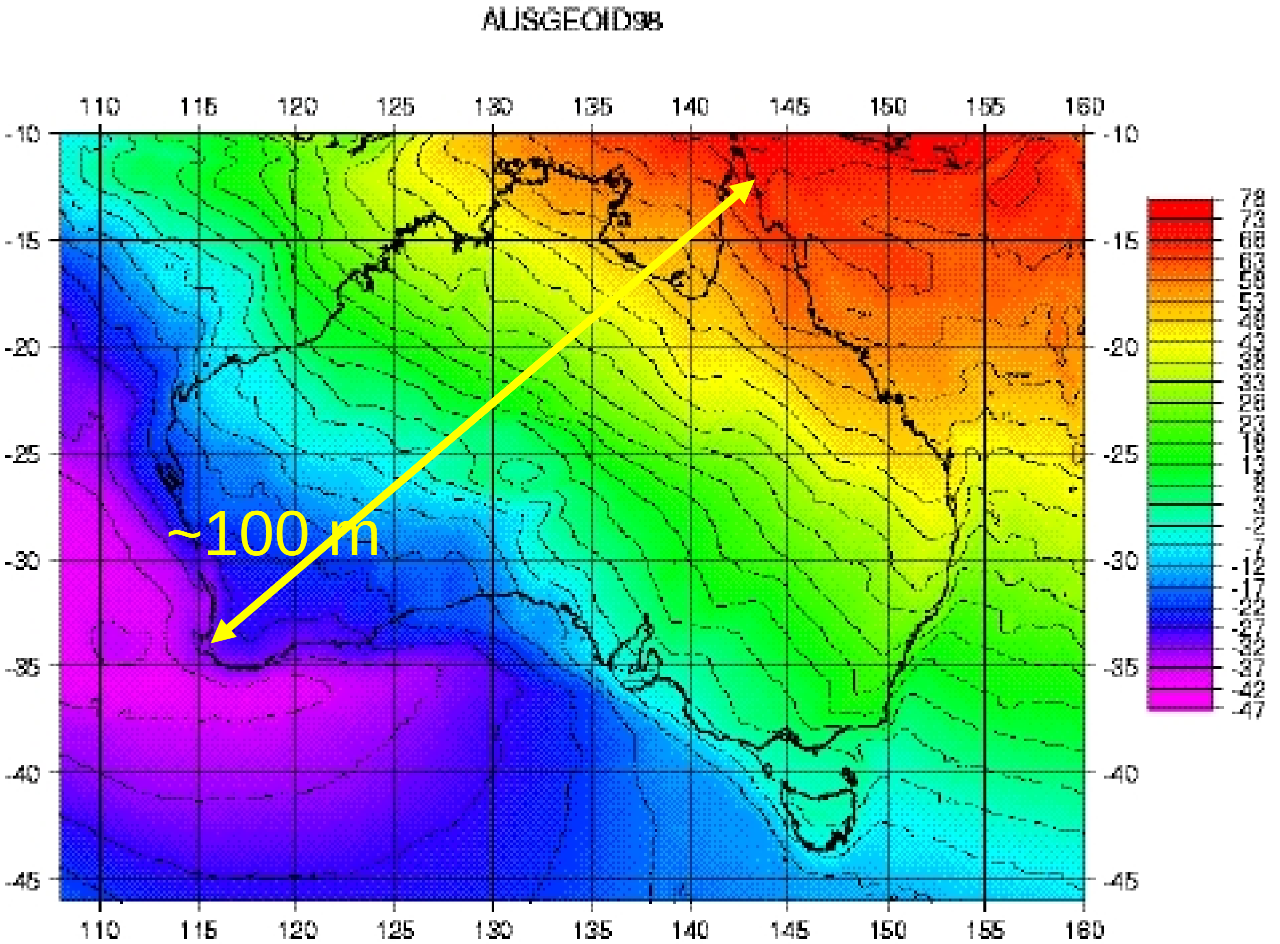


image source: National Geodetic Survey: http://www.ngs.noaa.gov/images/ngs/jpeg-geo/ww15mgh.jpg

Shape of Australian Geoid

AUSGeoid98 contour diagram



Datum Ellipsoids

- 'Datum', as generally used in GIS applications, refers to both the location of the centre of the fitted ellipsoid relative to the Earth (datum) and to the shape of the ellipsoid
- Ellipsoid (spheroid) parameters:

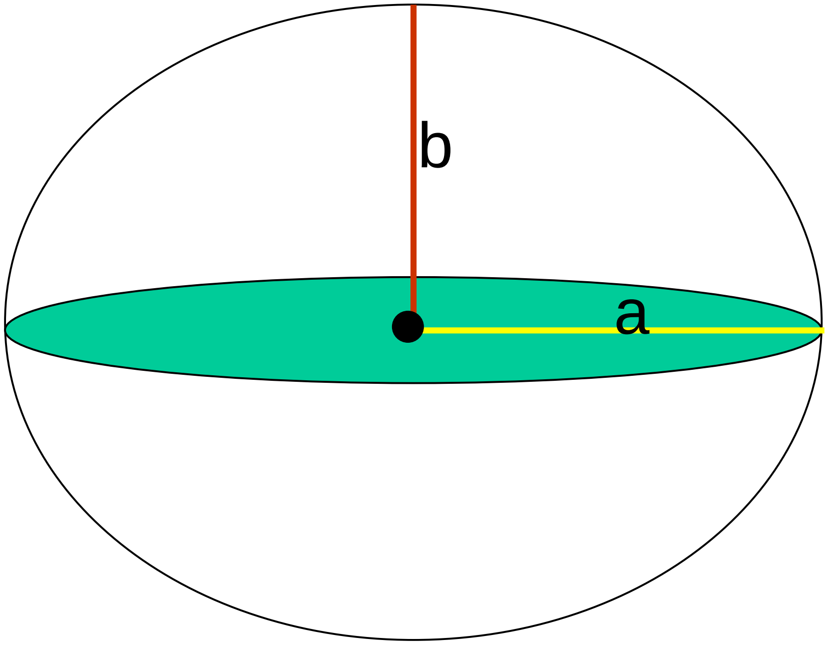
  a = semi-major axis (equator)

  b = semi-minor axis (polar)

  f= flattening = (a-b)/a

  (as f is very small it is generally given as:

  1/f = inverse flattening = a/(a-b)



- Example: WGS84 ellipsoid
  - a = 6378137.0 metres
  - b = 6356752.3142 metres
  - 1/f = 298.257223563

Global geocentric datum

- Based on centre-of-mass of Earth
  - but centre-of-mass varies with Plate motion
  - therefore is date-dependent

- **ITRF (International Terrestrial Reference Frame)**
  - centre-of-mass datum computed annually
  - uses GRS80 ellipsoid shape
    - (Inverse flattening = 298.257222101)

- WGS84
  - Centre-of-mass datum originally defined for GPS by NIMA
    - (US National Imagery and Mapping Agency)
    - Slight difference in ellipsoid flattening to GRS80
      - (Inverse flattening = 298.257223563)
- Has varied over time but is now close to ITRF

WGS84 – the ‘standard’ GPS datum

- Centre-of-mass datum defined for GPS by NIMA
- The gravitational model, and hence the centre is revised periodically:
  - currently based on EGM96 (Earth Gravitational Model 1996)
    - last updated 2004 (valid until 2010)
  - EGM2008 now under construction
    - may replace WGS84 as the datum name in GPS units
- Note that old (e.g. mid-1980s) GPS coordinates based on WGS84 will not exactly correspond in location to a modern GPS set to its WGS84 datum

Note also that WGS84 uses the zero meridian as defined by the Bureau International de l'Heure in Paris, based on a mean of compiled star observations from different countries.

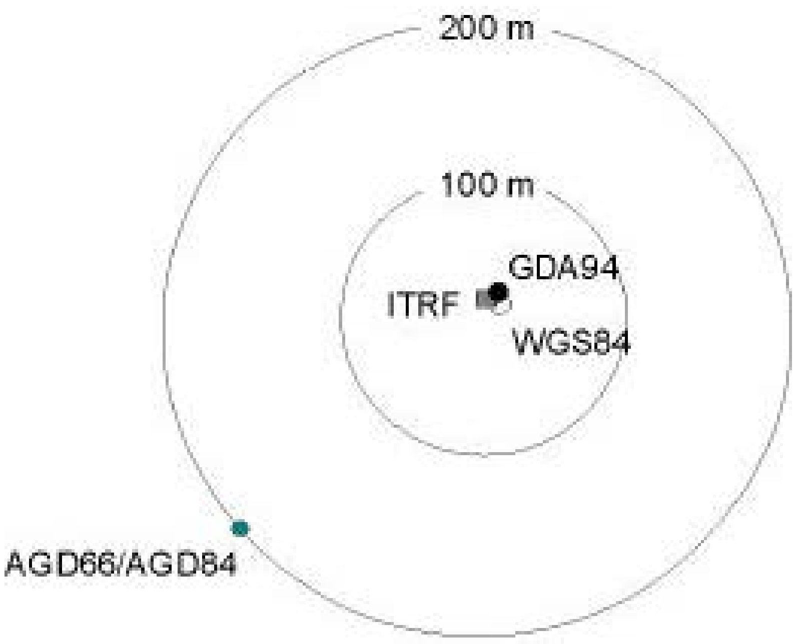
The WGS84 zero meridian is 102.5 metres east of the Prime Meridian that passes through Greenwich Observatory!

Australian and International Datums

- Australian
  - Older imperial map datum
    - Clarke ellipsoid
  - ‘Recent’ metric map datums
    - AGD66
    - AGD84
  - Modern metric map datum
    - GDA94
      - based on ITRF1992
      - fixed on 1/1/1994
- International
  - >50 datums in local use
  - e.g. USA
    - NAD27

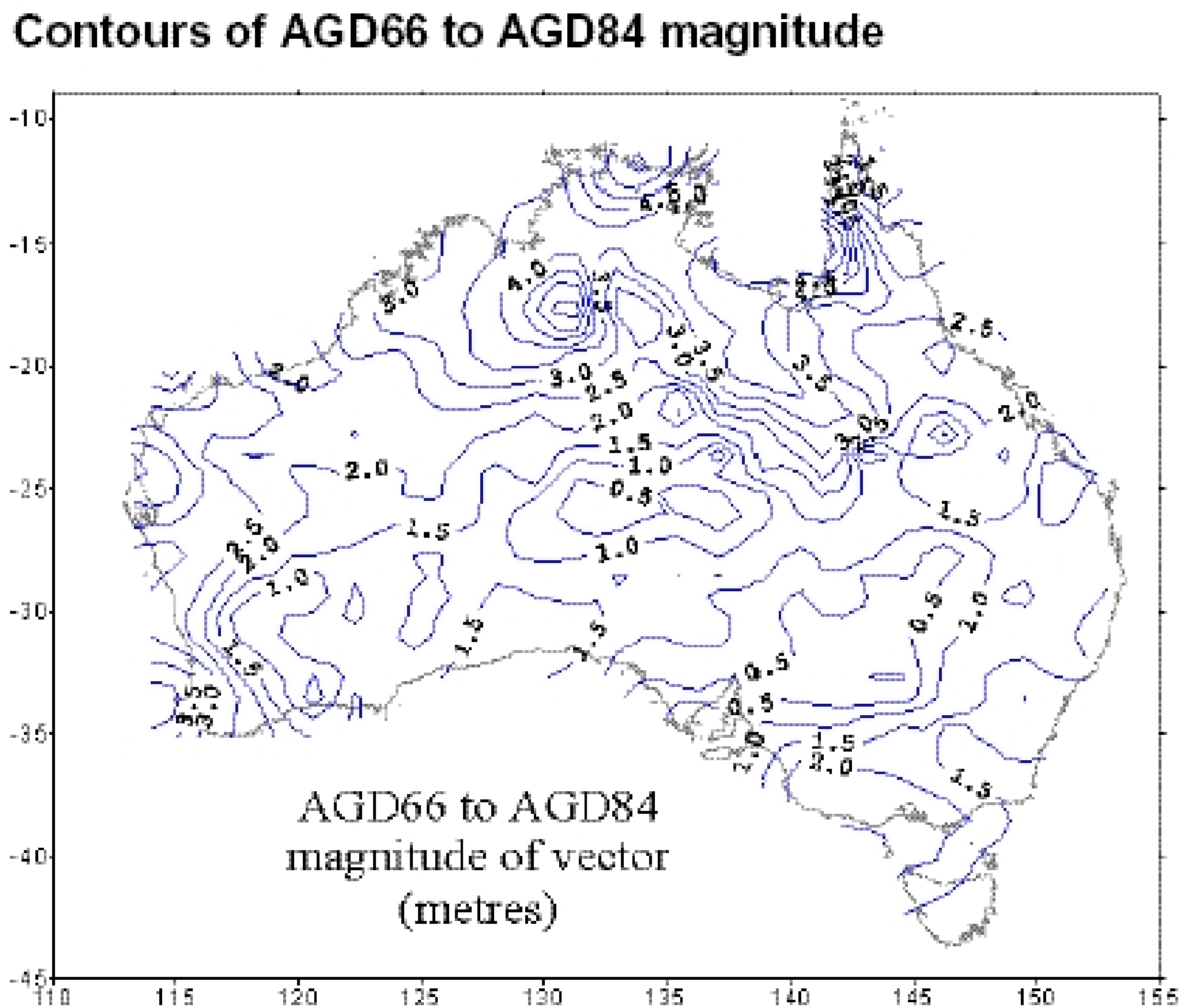
    South America
    - SAD69

GDA94 ≃ WGS84



AGD66/AGD84 comparison

- Maximum spatial difference is about 3 metres

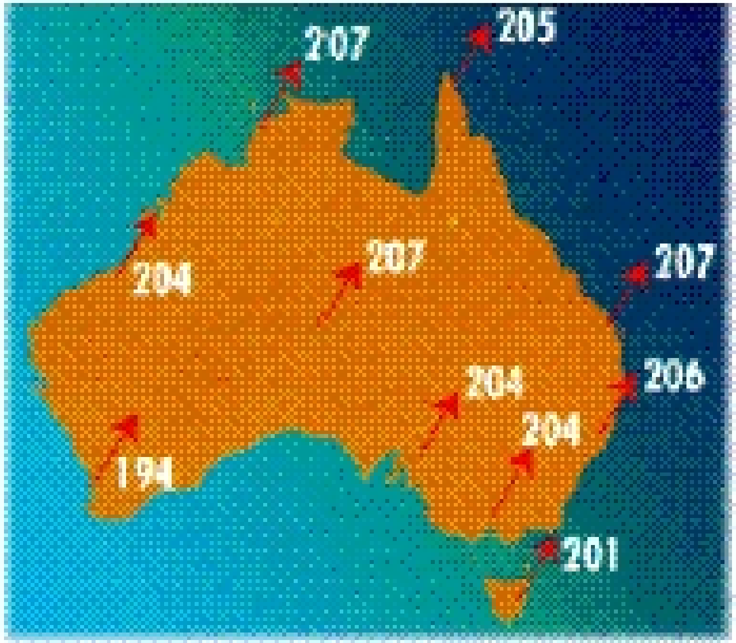


GDA to AGD comparison

GDA and AGD

ITRF92, on which GDA is based, was realised using Very Long Baseline Interferometry (VLBI), GPS and Satellite Laser Ranging (SLR) observations at 287 globally distributed stations (Boucher, 1993). However, the coordinates for Johnston, the origin station for the Australian Geodetic Datum (AGD), were based on a selection of 275 astro-geodetic stations distributed over most of Australia (Bomford, 1967). The adoption of this origin and the best fitting local ellipsoid, the Australian National Spheroid (ANS), meant that the centre of the ANS did not coincide with the centre of mass of the earth, but lay about 200 metres from it. Hence, the GDA94 coordinates of a point appear to be about 200 metres north east of the AGD coordinates of the same point.

The precise size and orientation of the difference will vary from place to place. More detailed information, including methods of transformation, is available in chapter 7.



- Maximum spatial difference is about 200 metres

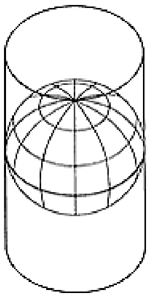
Projections

- The algorithm used to project map data that has been projected from the terrain onto the datum ellipsoid onto a 2D flat surface
  - e.g polar stereographic projections
    - e.g. as used for continental wander path reconstructions

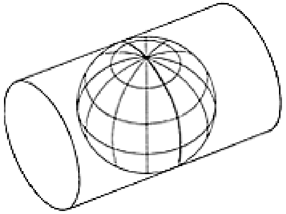
- Most common map projection:
  - Universal transverse mercator (UTM)
- Others
  - conic, polyconic, gauss-kruger (similar to UTM), etc...

Mercator projection

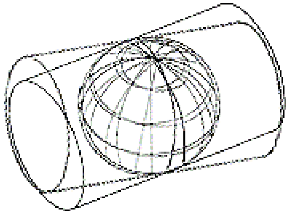
- Mercator Projection
  - Cylinder tangent to equator



- Transverse Mercator Projection
  - Cylinder tangent to line of longitude

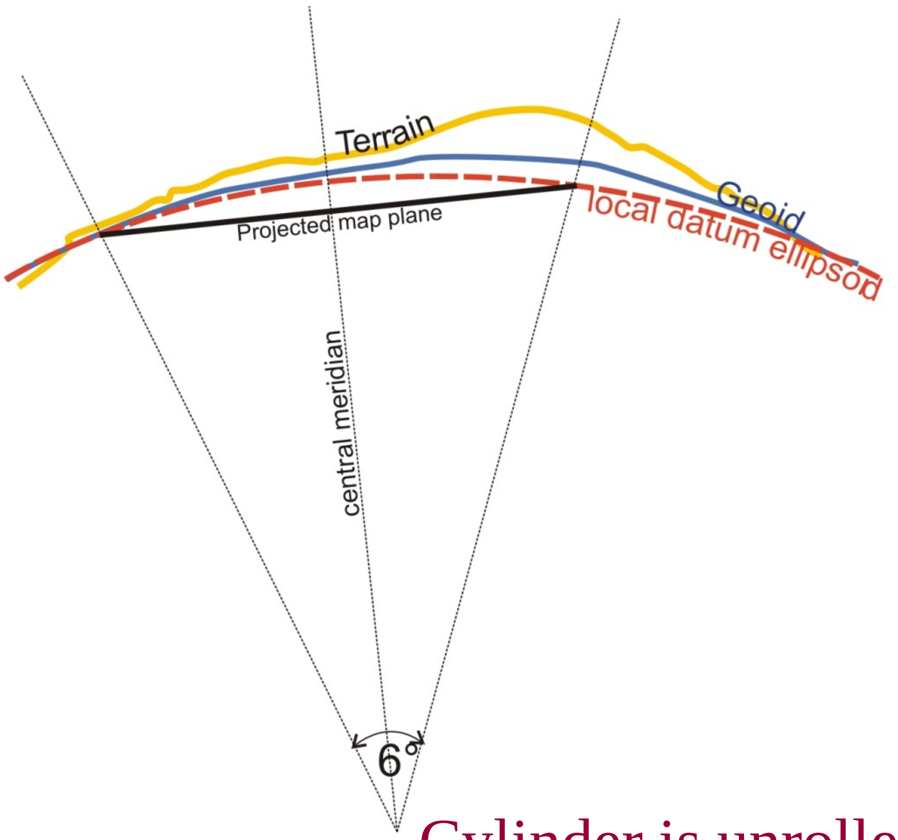


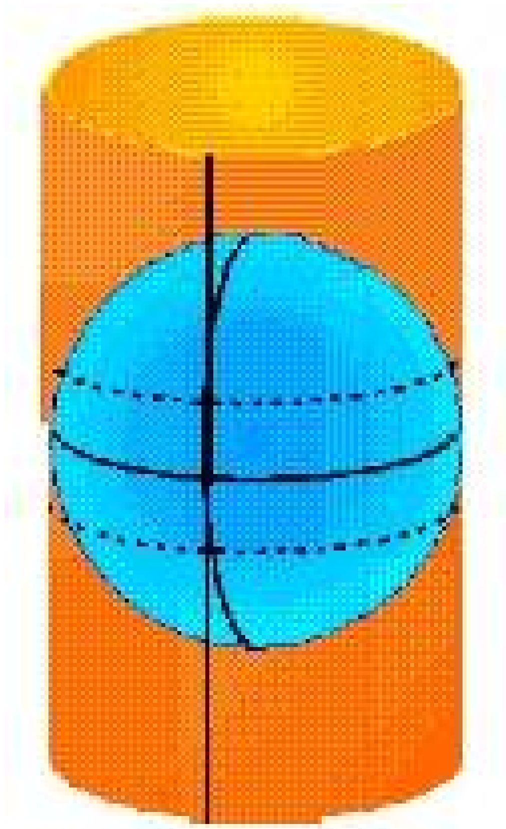
- Universal Transverse Mercator projection**s**
  - standard set of 120 projections around the globe
    - 60 x 6º zones; separate definition of N & S hemisphere



UTM projection

- Projection onto a cylinder tangent to a line of longitude ('Central Meridian' and touching the equator at a point





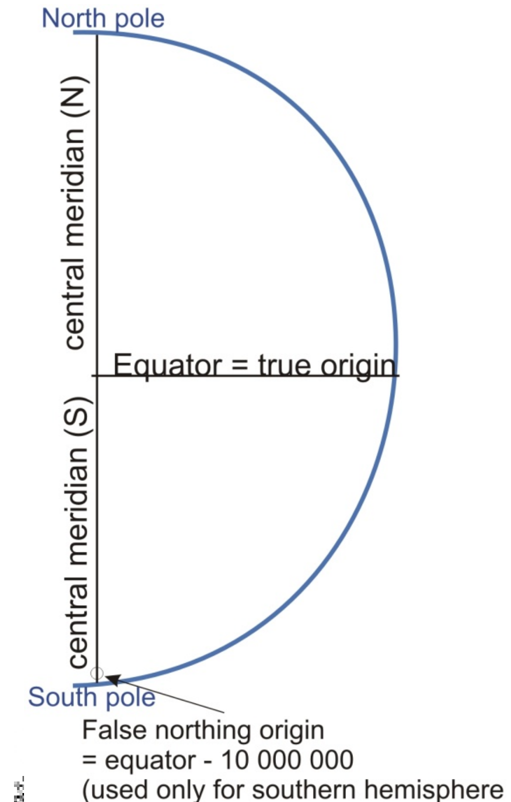
Cylinder is unrolled to give 2D map
(only accurate close to the Central Meridian)

UTM zones

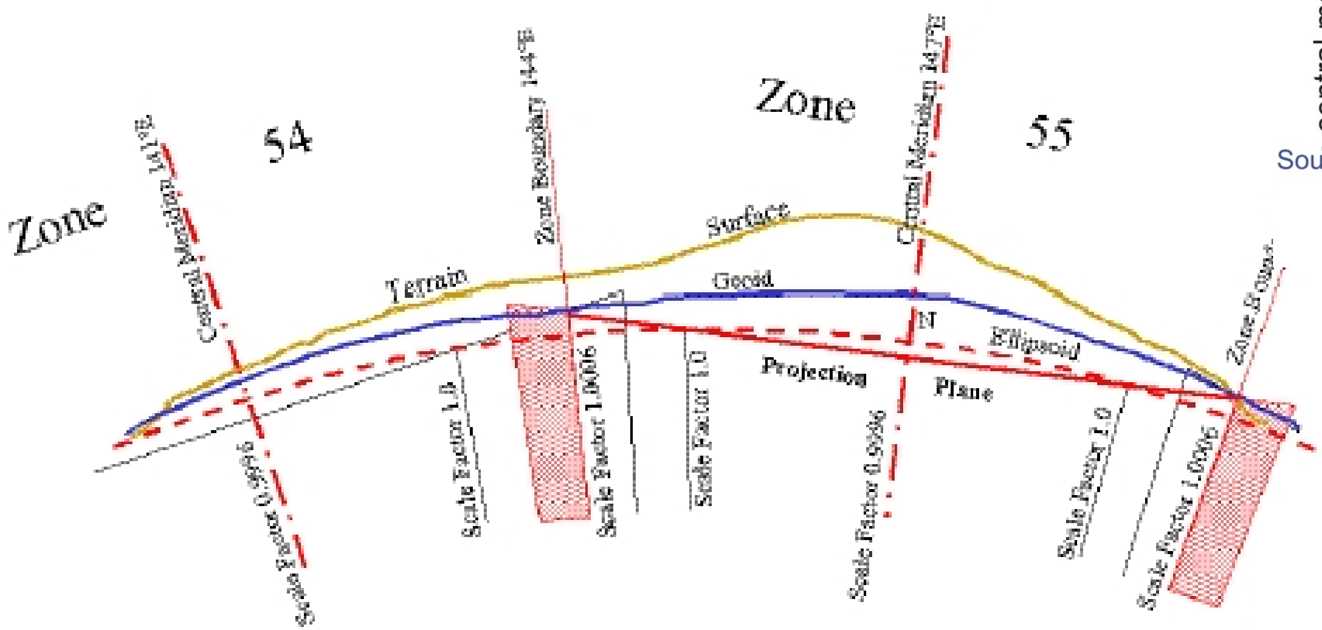
– 60 northern and 60 southern zones

Definition of UTM zones

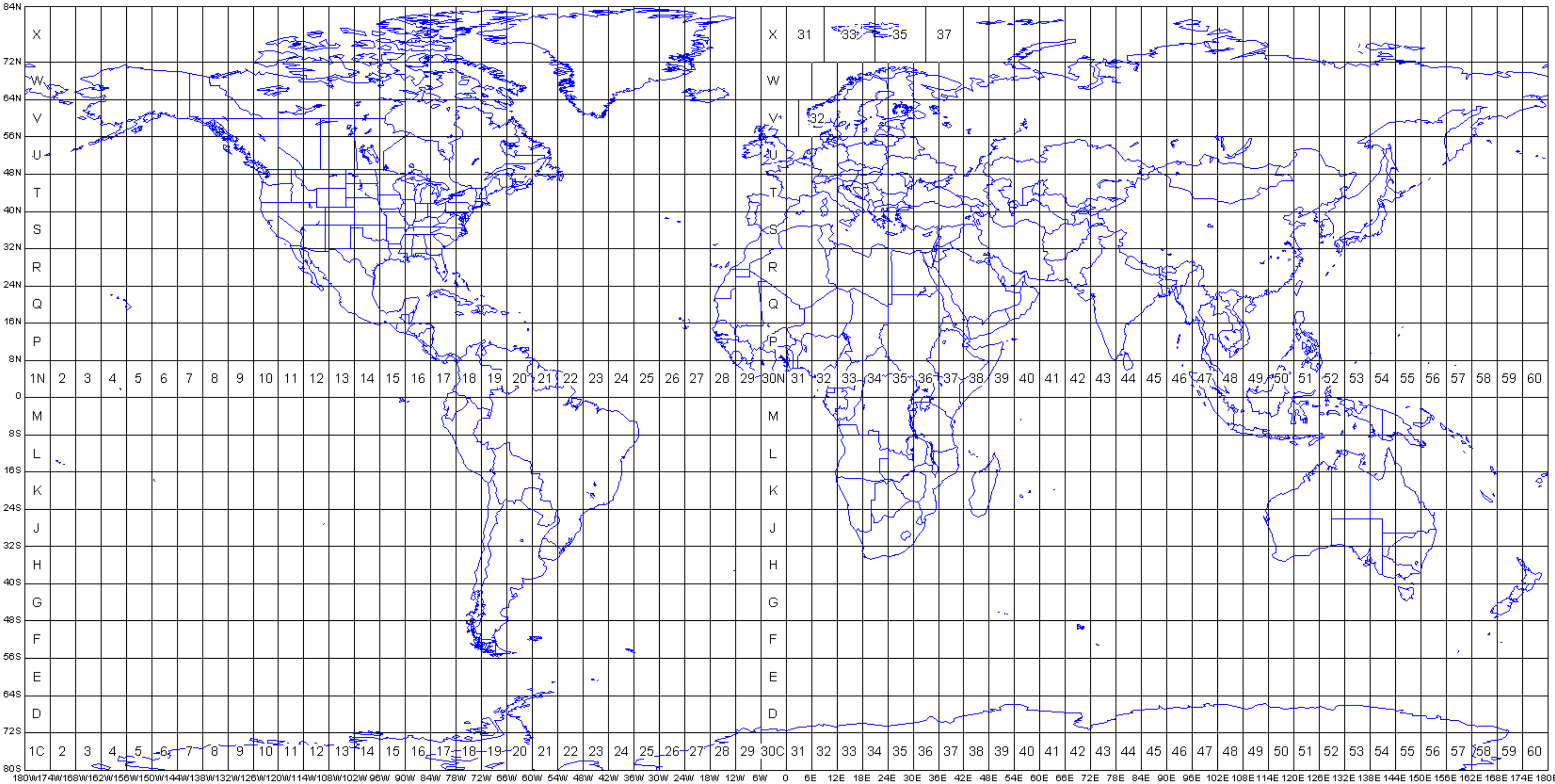
Longitude of initial central meridian (Zone 1)	177° W
Zone width	6°
Central Scale Factor	0.9996
False easting	500 000 m
False Northing (S hemisphere)	10 000 000 m



Cross section through two MGA zones



Global UTM zones



Coordinate labels in databases

- Coordinate labels on spreadsheet or database columns should indicate the projection AND the datum
  - Assume that at some point that the data will be used by someone else
  - In the example shown at top right it is a reasonable guess that the projection is UTM – but what is the datum?
    - local alternatives are WGS84, Corrego Alegre, or SAD69
  - The example at lower right at least indicates that, in this case, the UTM guess is correct, and the datum is Corrego Alegre

PNT	X	Y	Lithotype
01	298843	8097407	2
02	298871	8097485	2
03	298909	8097512	2
20	298969	8097808	4
06	298987	8098281	2
07	298995	8098173	2
08	299000	8098096	2

PNT	Xutm_COA	Yutm_COA	Lithotype
01	298843	8097407	2
02	298871	8097485	2
03	298909	8097512	2
20	298969	8097808	4
06	298987	8098281	2
07	298995	8098173	2
08	299000	8098096	2

The UTM zone should also be referenced somewhere

Australian map grids (projections)

- Yard grid
  - Clarke ellipsoid
  - e.g. Gympie 1:250000 sheet
- Modern metric maps
  - AMG66
    - AGD66
  - AMG84
    - AGD84
  - MGA94
    - GDA94
      - based on WGS84

Australian UTM zones