APSG Geodetic Workshop (Introduction)

Jim Cain
APSG Immediate Past Chair and Member,
OGP/EPSG Geodesy Subcommittee
jim.cain@cain-barnes.com

February 28, 2007

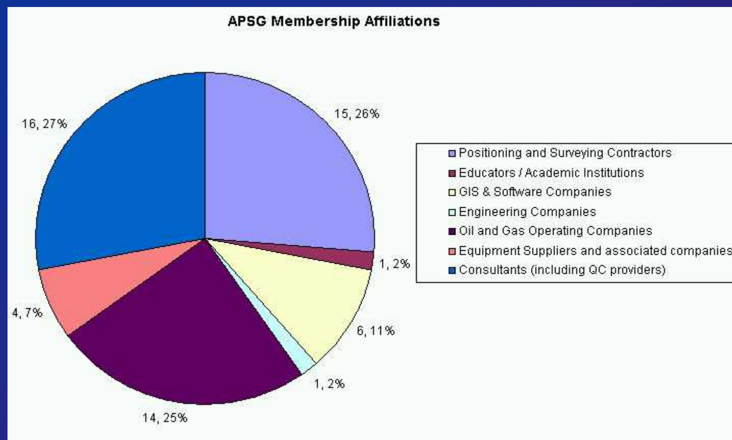
Cain & Barnes, L.P.
12418 Stafford Springs Dr
Houston, Texas 77077
1+832-215-5551
www.cain-barnes.com

www.apsg.info

APSG – Who Are We?

- The Americas Petroleum Survey Group (APSG) is an unincorporated association of individuals who desire to exchange geodetic and cartographic information relating to worldwide petroleum development. The purposes of the APSG are to advance survey technology relative to the worldwide petroleum industry and to disseminate information to APSG members in respect of worldwide petroleum geodesy, surveying, cartography, and spatial data management
- A primary APSG goal is to enhance education and awareness of geodetic issues within the GIS and G&G communities within our industries

APSG Membership Distribution by Sector



Recent APSG Initiatives (1)

- Guidance Note(s) on Geodetic Applications Software
  - First such GN limited to “Precision and Presentation” w/ Version 1.0 released following 15 Nov 2006 meeting
    - Stresses the requirement to match EPSG db terminology
    - Stresses EPSG dbase as a primary source for compliant algorithms, CRS, etc.
    - Does not express requirement for users to have unique object codes (per object type) as in EPSG db, but suggests it
  - Future Software GNs are expected to address other user concerns, but . . . .
    - Are not anticipated to cover detailed “Audits” of software routines
    - Exact topics to be covered in these Guidance Notes is still under review
  - Input is being sought from Software Developers and Suppliers as well as End Users.

APSG Guidance Note on Geodetic Software “Precision and Presentation”

Guidance Note

for

Geodetic and Cartographic Applications

(Precision and Presentation)

Revision history:

Version	Release Date	Amendments
1.0	15 November 2006	Initial Release
1.1	16 January 2007	Corrections and expansions in symbology suggested at November 2006 annual meeting.

Contents

Recent APSG Initiatives (2)

- Guidance Note on Geodetic Transformations for the Gulf of Mexico
  - Version 1.0 released 8 March 2006
    - NADCON CONUS recommended for all O&G work in US GoM
    - Superseded transformations (JECA, EnSoCo, NIMA) provided for historical reasons, should they be needed on legacy data
    - Use of EPSG dbase terminology used and stressed.
      EPSG codes are given for all transformations in the Guidance Note
  - Version 2.0 released 15 November 2006
    - Additional 2 JECA transformations for Mexican waters
    - Accuracy assessments of all JECA transformations for GoM
    - A few minor corrections brought about by user request

APSG Guidance Note on Geodetic Transformations for the Gulf of Mexico

Guidelines
for
Geodetic
Transformations to
NAD27 for use in
the Gulf of Mexico

APSG
Americas Petroleum Survey Group

Revision history:

Version	Release Date	Amendments
1.0	8 March 2006	Initial Release
2.0	15 November 2006	Add JECA Campeche transformations; add accuracy assessments to early transformations; correct typo errors in tfm steps from NAD27 > NAD83 > NAD83(HARN) > WGS 84 on page 2

Contents:

Current APSG Leadership (February 2007)

- Chair
  John Conner (EnSoCo, Inc.)
- Vice Chair
  Bruce Carter (BP Americas)
- Secretary/Treasurer
  Hugh Beattie, Exploration Geodesy, Inc.)
  Immediate Past Chair
  Jim Cain (Cain & Barnes, L.P.)

- Membership and Technical Advisory Committees Chair
  Barry Barrs (ExxonMobil)
- Education Committee Chair
  Jon Stigant (Devon Energy)

Next APSG meeting will be April 25th, 2007 at Schlumberger, Houston

Today's Workshop Schedule

Workshop: **28th February 2007, 1:00 to 4:15 p.m.**

1. ***Introduction:***
   Jim Cain
   APSG Immediate Past Chairman
   Email: jim.cain@cain-barnes.com

2. ***Geodesy and Projections***
   Presenter: Jim Cain
   Cain & Barnes, L.P.
   Houston, Texas.
   Email: Jim.Cain@cain-barnes.com

3. ***Positioning Issues Related to Seismic Data Loading***
   Presenter: John Conner
   EnSoCo, Inc.
   Houston, Texas
   Email: jconner@ensoco.com

4. ***The Challenge of Enterprise-wide Spatial Data Management***
   Presenter: Jon Stigant
   Devon Energy
   Houston, Texas
   Email: Jon.Stigant@dvn.com

2007 ESRI Petroleum User's Group Workshop

Geodetic Datums and Projections as they apply to the Petroleum Industry

Jim Cain
APSG Immediate Past Chair and Member,
OGP/EPSG Geodesy Subcommittee
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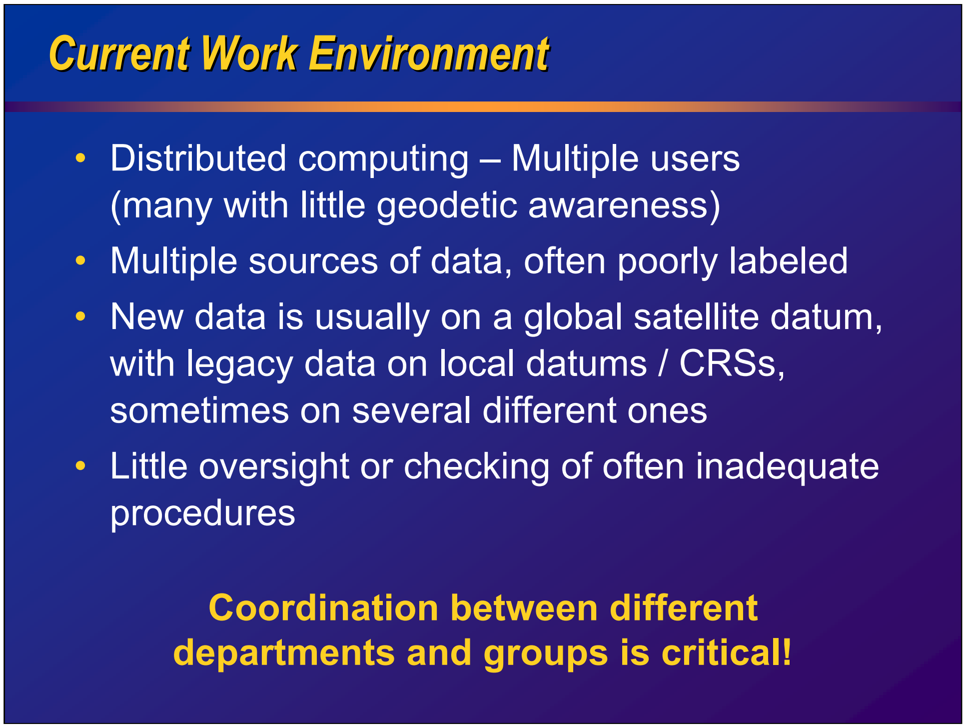
Our task today is to convince you that ...

•

Geospatial Data Management is Important!

I.e.,

Why you should care about Geodesy



Users of geospatial data maybe as varied as lawyers, IT support, interpreters, drillers and management – plus of course geologists and geophysicists.

All have different issues and purpose for using the data, with different mapping requirements.

But all should share a common goal, successful discovery and enhanced production

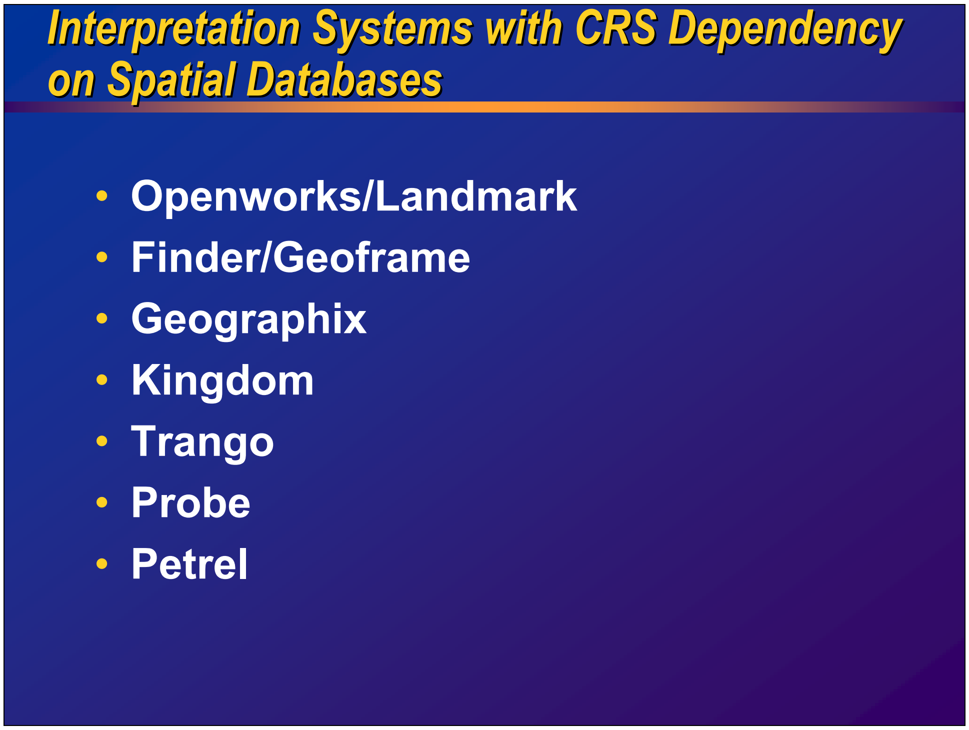
Without mutual interdepartmental cooperation this strategic goal is at risk.

Conventional thinking is …

"In the past, the main source of positioning risk was during data acquisition"

There still remains the risk of positional errors during data acquisition – however . . . .

"Today, the main source of positioning risk is no longer data acquisition, but data management!"



There are a myriad of databases used for interpretation and for provision of seismic, well and boundary data.

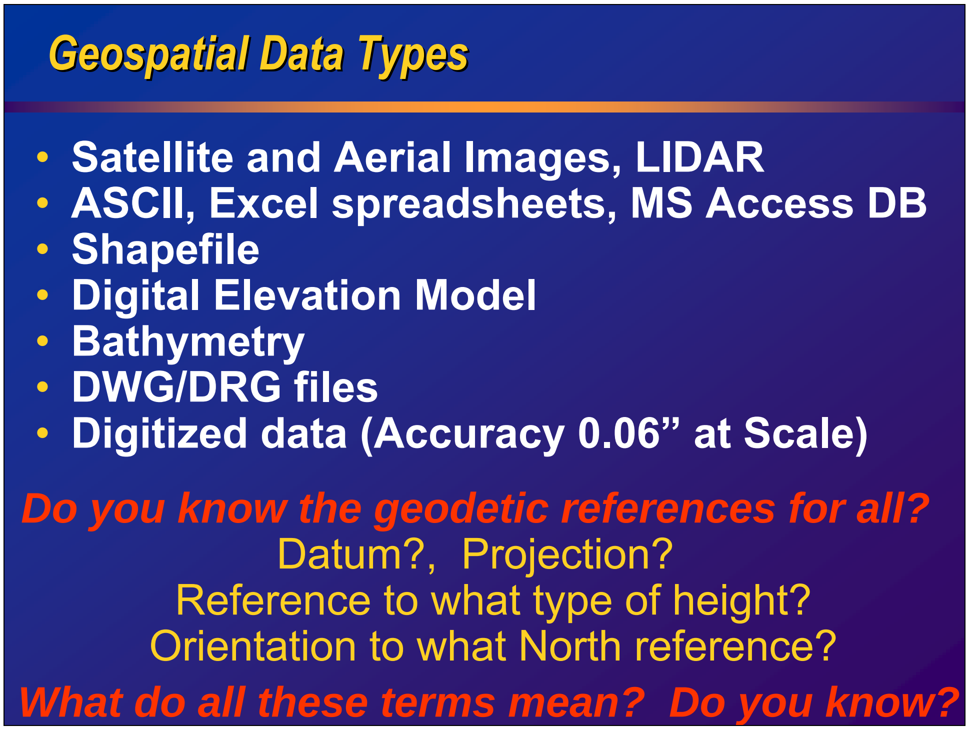
Many of these applications developed coordinate management algorithms as an afterthought, and the methodology and user interfaces are fraught with imprecise language and options. Many do not allow you to see the parameters that are being used for the datum and projections utilzed. Insist that the vendor releases this data. Work through your administrator, but do not ignore or fail to validate these data.

If you use these systems, get someone geodetically knowledgeable to check your geospatial referencing work (selecting datums, GeogCSR, ProjCRS, Transformations, etc.)

There are numerous mapping and coordinate transformation and conversion software suites.

In addition to those listed on the slide, there are other suppliers (such as Mentor Software) that provide underlying geographic calculation software used in other applications such as those shown on the prior slide).

Each one has strengths and weaknesses. Setting up the parameters is particularly important, and often difficult, and you may need to get expert assistance.



There are many different data types, that we want to bring into our GIS applications. Each one must be examined for proper geospatial references and matched appropriately to the project Datum / GeogCRS and/or Projection / ProjCRS, in order for the features to match . . AND to have them in the right locations.

Satellite and Topo sheet image data must be orthorectified – which means that the pixels are scaled and adjusted for height distortions to match the datum and projection.

Many programs do not properly re-adjust TIF images to the project datum / GeogCRS and projection / ProjCRS.

If you use Excel and ASCII file formats for input and output from coordinate conversion programs, be sure to annotate the datum / GeogCRS and projection / ProjCRS in the file name, or in the property part of the file. If you convert the data, be sure to update the name and properties for late users.

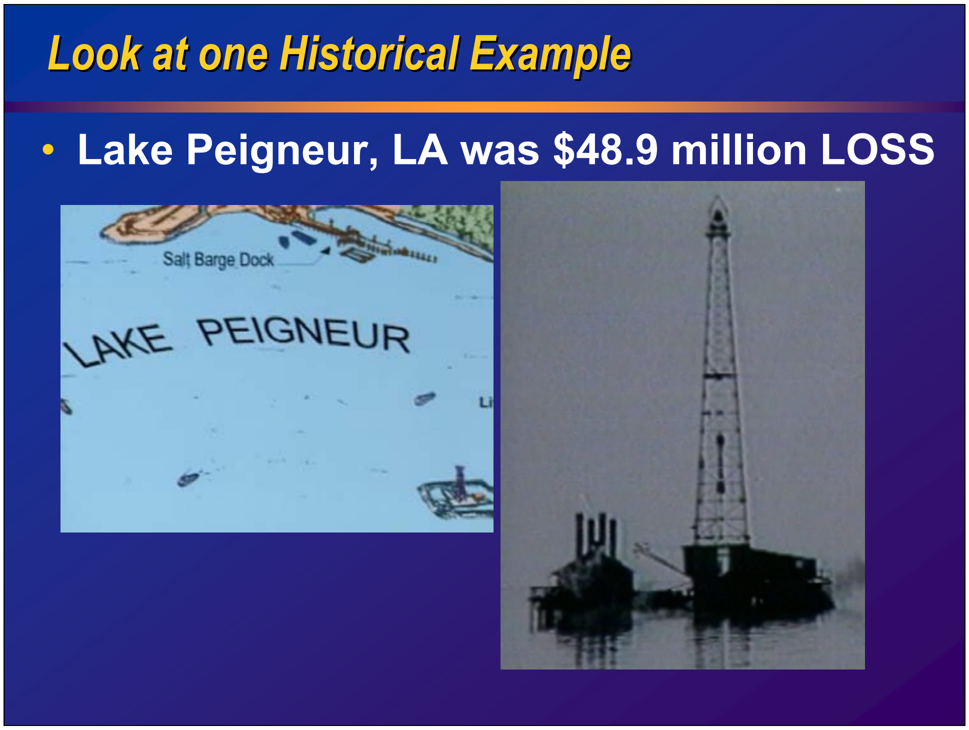
A very rigorous audit trail via the associated metadata is vital – you will not remember later what you did, nor will anyone else be able to review your work in case of problems.

Geospatial Data is the basic framework that …

ties all aspects of the Upstream together:

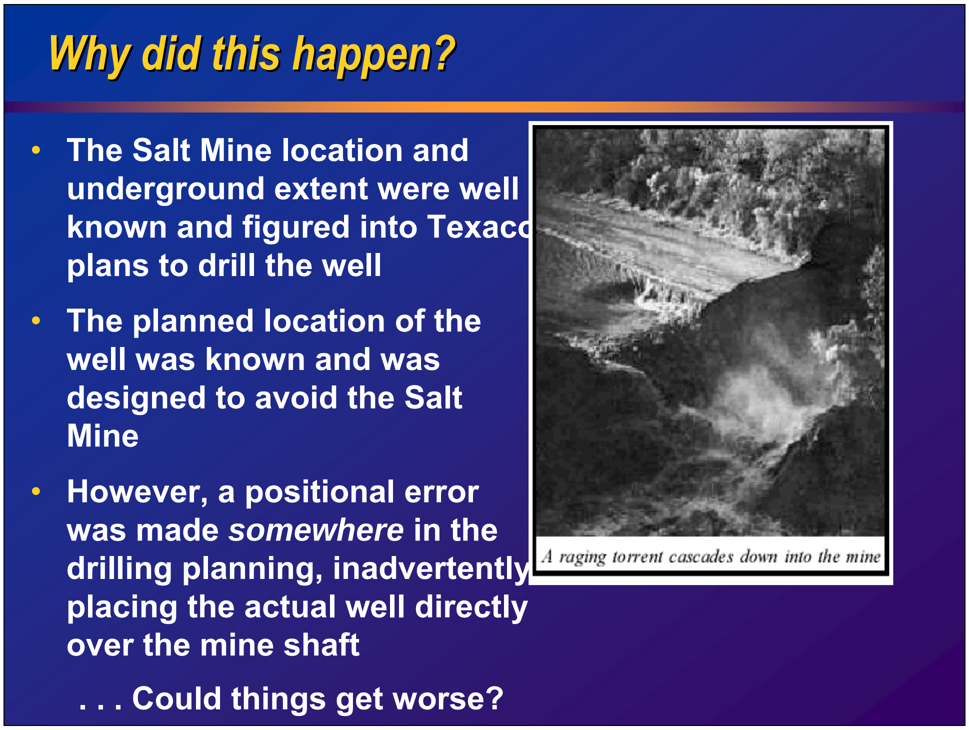
- **Lease negotiations, prospect delineation, and permitting**
- **Seismic data are planned, acquired, and managed geospatially**
- **Well locations are selected relative to seismic**
- **Site surveys often run to ensure safety when the wells are drilled**
- **Wells are drilled based on results of above**
- **Facilities are often placed close to the wells**
- **Pipelines extend from wells to facilities**
- **Prospect handover or relinquishment**

This framework applies to surface, subsurface, and subsea



A brief movie extracted from the History Channel DVD played here shows what devastation can occur by drilling a well in the wrong place (used with permission)

(This Short movie was assembled from History Channel original for geodetic training by Stuart Jackson of S2S Systems and is used with permission)



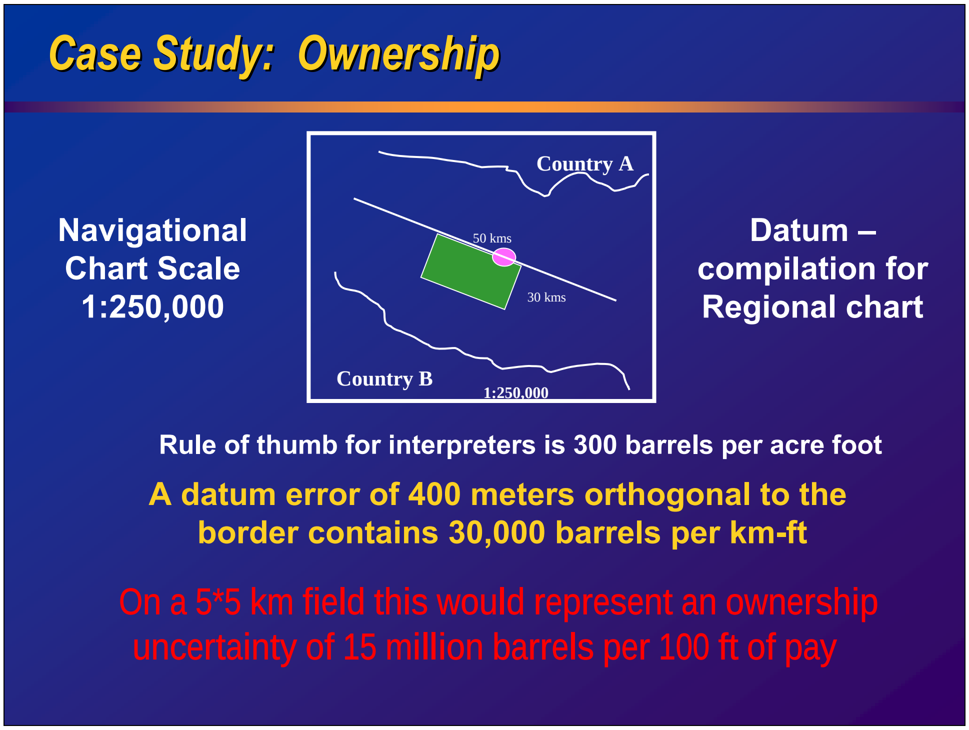
The conclusion of the brief History Channel History Channel movie extract is played following this slide

(This short movie was assembled from History Channel original for geodetic training by Stuart Jackson of S2S Systems and is used with permission)

… with a significant positional error!

- Had the rig’s positional error been discovered before drilling:
  - the mine would still be operating
  - the lake would be fresh water
  - the lake would still be 10 to 20 feet deep instead of 1300 feet deep
  - and the O&G operator would have saved $48.9 million dollars.

Let’s now see the end of the Lake Peigneur movie



Scenario is the median between two countries

Line defined on published chart at 1:250,000

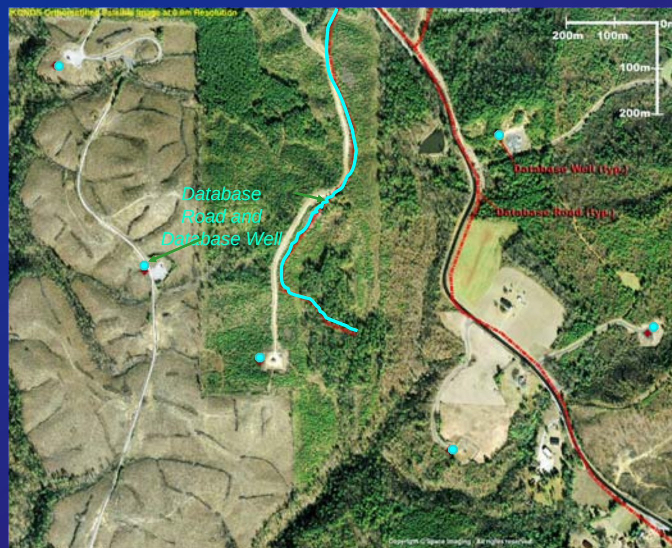
Datum is undefined due to scale – chart is compilation of data from several surveys in different datums. Charts are designed for safety of shipping not ownership of oil – a very common scenario when downloading or digitizing data

How much oil will you own?

Does the PSC define the datum?

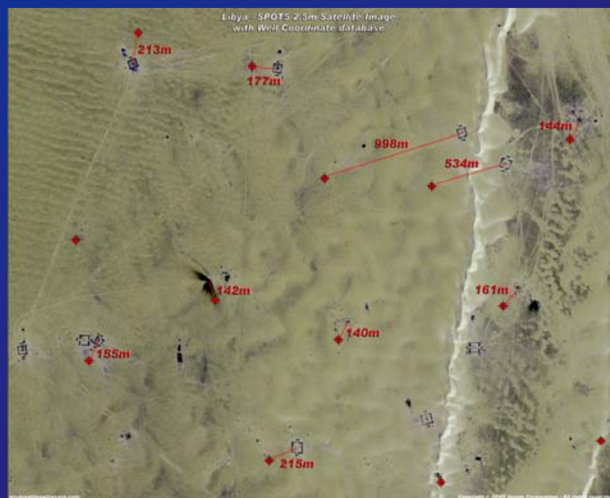
Will there be delays due to disputed ownership?

Infrastructure and Wells in Wrong Locations



Use of Photo Image courtesy of Satellite Imaging Corporation

Case Study: Well Positioning Database



Use of Photo Image courtesy of Satellite Imaging Corporation

Well position errors of 140 - 1000m. Many of these caused by incorrect application of geodesy!

Lessons learned

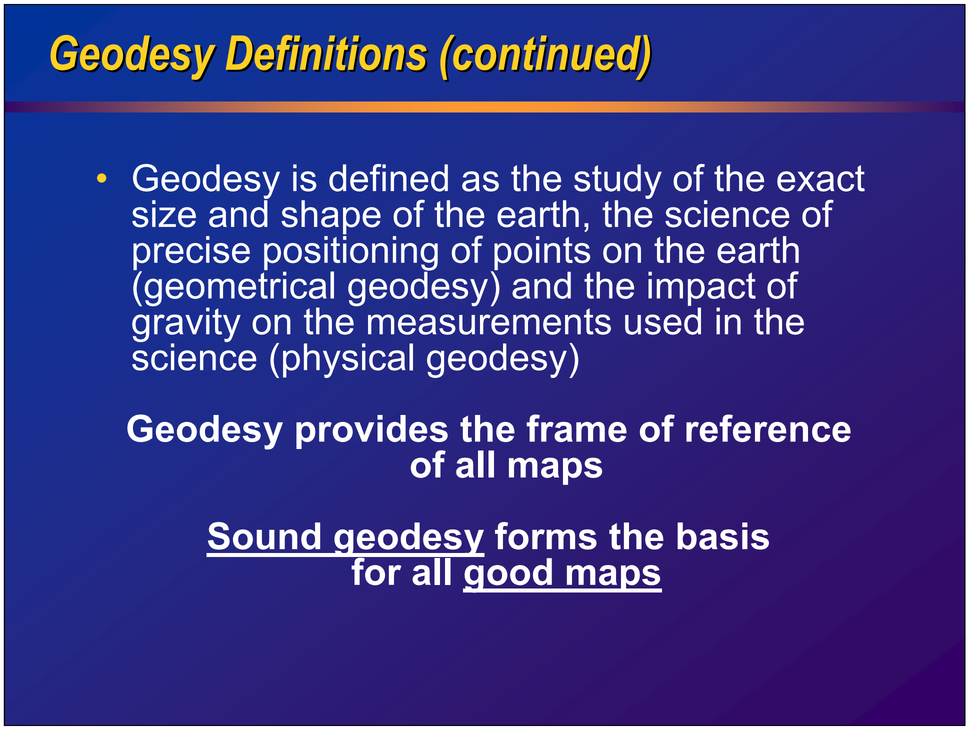
- Positioning errors can and do cost companies millions of dollars
- These same positioning errors can also put people in harms way

Before we go further – a few Definitions

- **Literally: Geodesy (γη = Earth δαιω = 1 divide) The science of the measurement and mapping of the Earth's surface. (**F. R. Helmert, 1880)
- **Branch of Mathematics dealing with the figure and area of the Earth or large portions of the Earth. (**Concise Oxford Dictionary)

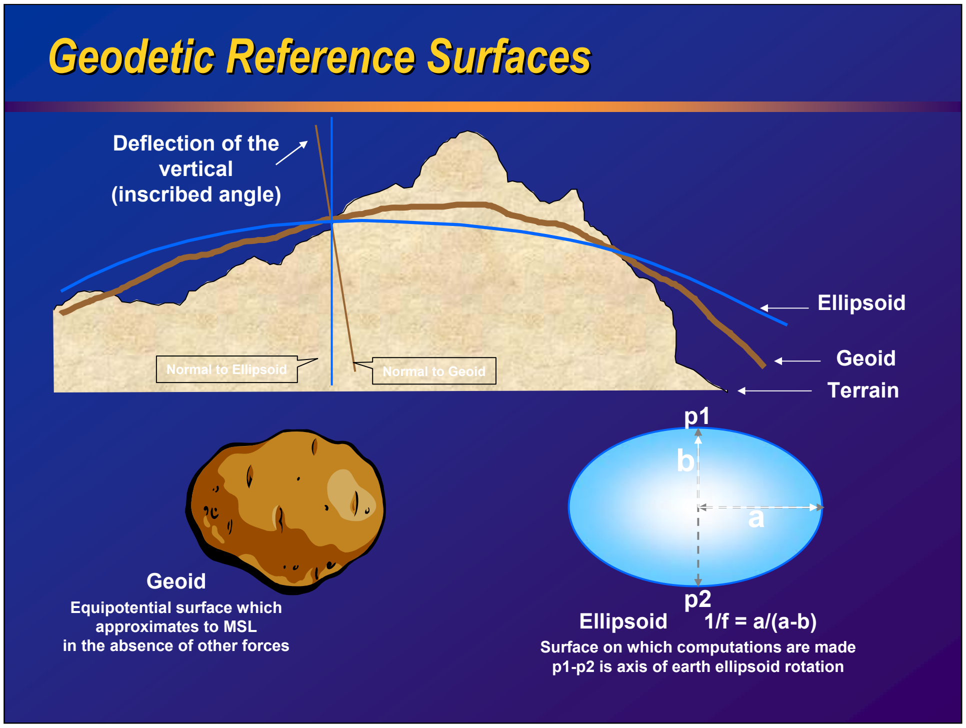
There are many different definitions for Geodesy, but the above two capture the essence.

Geodesy is a geoscience – and one that is highly dependent on mathematics



As shown here, geodesy is further divided into specific subtypes, There are intertwined.

There has been a great increase in the use of Satellite Geodesy within the past twenty years (and particularly the last dozen years) due to advances in GPS and associated measurement techniques.



This slide represents the fundamental issues of establishing a Geodetic Datum.

In making any sort of measurement to define the shape of an Ellipsoid or to define a Datum-related Geographic Coordinate Reference System (GeogCRS) with resulting latitude and longitude values, astronomic and gravitational measurements are taken or used. The localized gravitational " pull " on the instrument's plumb bob or level effects the values of the measurements being used, and the assumption is made that the ELLIPSOID and GEOID are coincident, or their separation is somehow defined.

This results in a term called "Deflection of the Vertical" which has a significant affect on these measurements. Different locations produce different deflections (e.g. the flat areas at Meades Ranch, Kansas for NAD 27 , the Himalayas and Pacific trenches near Tokyo Observatory for Tokyo Datum).

Geodetic Terminology (ISO compliant)

- Topography / Terrain (= actual earth surface)
- Geoid (= equipotential earth's surface ~ MSL)
- Ellipsoid / Spheroid = Mathematical figure used for computations
- Coordinate System (*only* a system of axes in ISO)
- Prime Meridian (the meridian that is set to zero for a given datum)
- Geodetic Datum
  - Local / Astrogeodetic Datums
  - Geocentric Datums / Global Datums
- Ellipsoid and Datum are NOT synonyms!
  - **Assuming otherwise can lead to costly mistakes (as we will show later)**

Basic Geodetic Terminology

Topography = The actual detailed surface of the earth; i.e., the surface upon which we walk.

Geoid = The mean equipotential surface of the earth; that is, parallel to mean sea level (MSL) or the surface along which water would naturally flow in the absence of other forces.

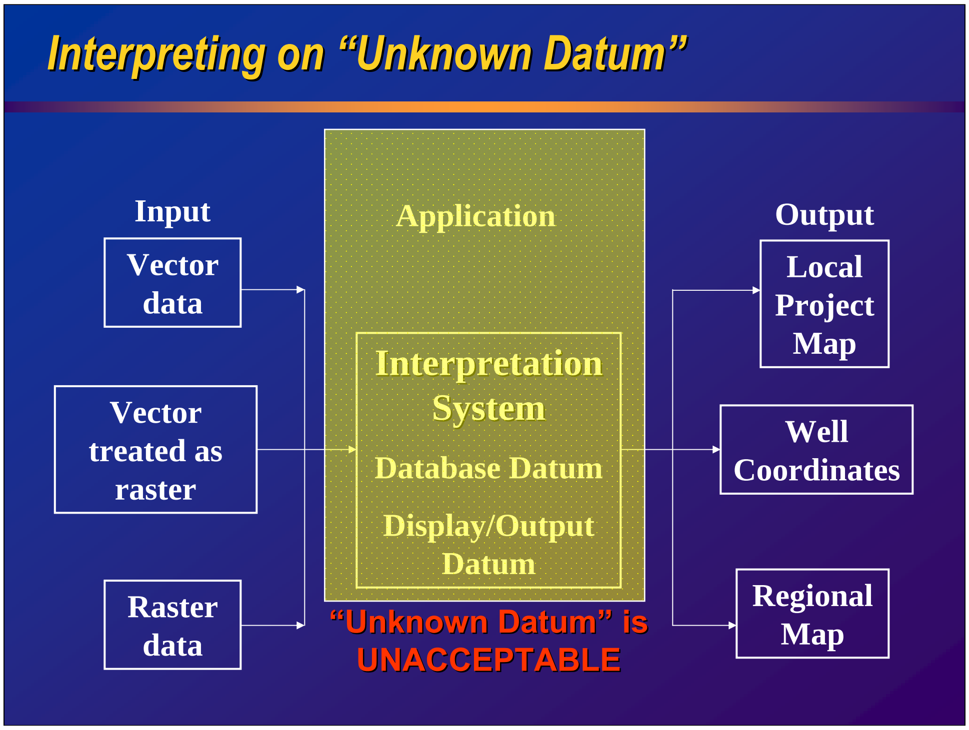
Ellipsoid (sometimes called "Spheroid") = A "mathematical surface" which can be utilized to approximate the Geoid for mathematical calculations. This is almost always an ellipse that has been rotated to form an ellipsoid. In a very few cases this is a circle rotated to a sphere, hence the historical term "spheroid.".

Coordinate System: A set of axes, their names, orientations and abbreviations. In ISO terminology, a Coordinate System is not a mapping system.

Prime Meridian is a datum's zero meridian. Most geodetic Datums utilize Greenwich as zero longitude. However other datums use principal cities in the area served by the Datum (Examples include Paris, Rome, Bogota, Djakarta as well as others.)

Geodetic Datum: A geodetic datum comprises a reference ellipsoid and a prime meridian. It does not have axes and is not a system of mapping

VERY IMPORTANT DISTINCTION: Ellipsoid and Datum are NOT synonymous! The same reference Ellipsoid may be used with several different Geodetic Datums, each datum associated with the fit of that ellipsoid to the earth. Thus stating the Ellipsoid is not sufficient to identify the geodetic Datum nor its associated Geographical Coordinate Reference System (GeogCRS). Costly errors can occur when the wrong datum is "assumed" based only on known ellipsoid.



"Unknown datum" allows both regional and local projects but means that all data must be prepared properly before loading.

Data loading paths are uncertain. Datum and projection are often not specified for new or archived input data

Reloading of data upgrades requires a huge memory test (what did we do last time..?) of technical staffs busy with their 'normal' work

Assumes that all data loaders and IT support staff understand the need for rigorous record keeping even allowing that they understand the principles of geodesy and cartography involved

Assumes interpreters understand the geodetic requirements for labeling maps and or the way to figure out the actual datum of the data, when selecting a well location

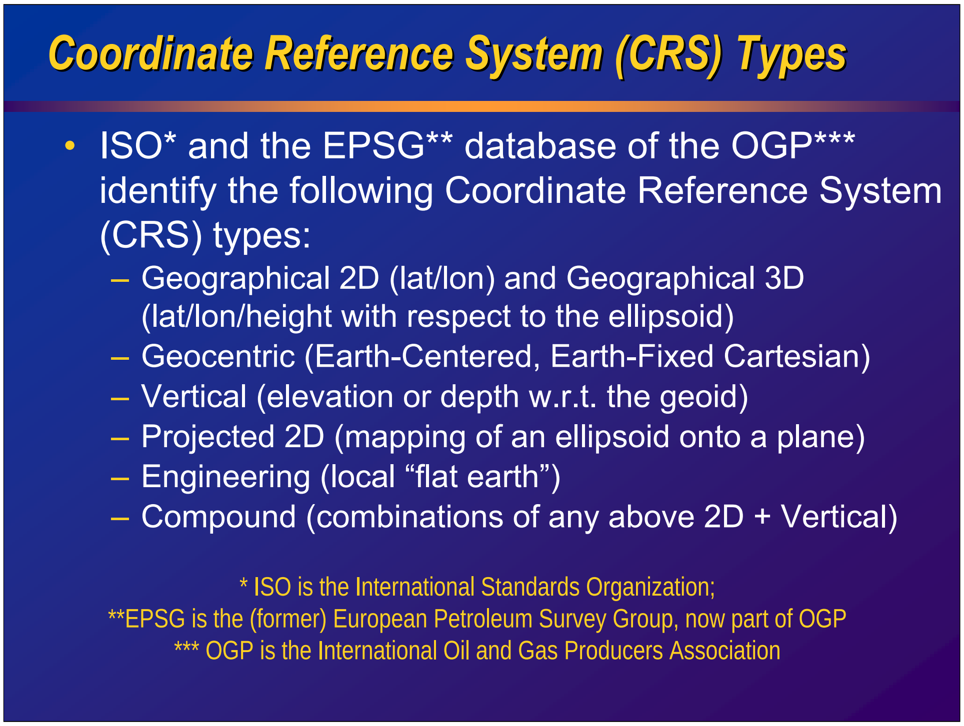
The reality is that this process, or lack of procedures represents a massive financial risk to a corporation. In one case a block boundary misplaced by several hundred meters created an apparent transfer of reserves of several million barrels of oil.

Datums

***** WARNING ******

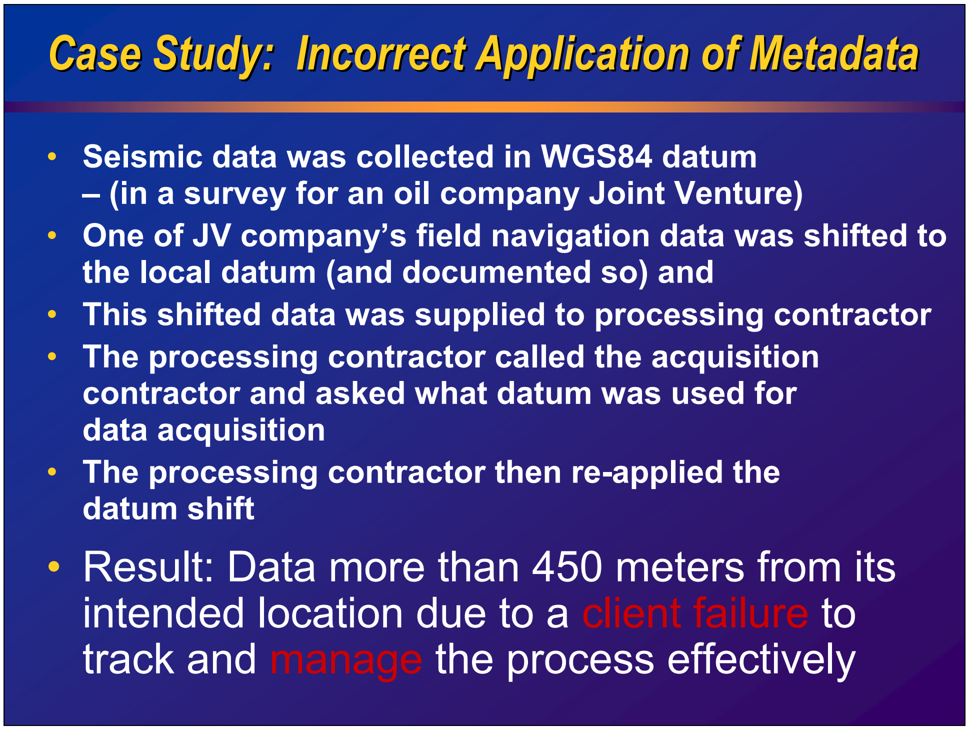
THERE IS ONE ESSENTIAL THING THAT YOU NEED TO KNOW ABOUT DATUMS…..

YOU NEED ONE!



Geographic 2D / Geographic 3D Coordinate Reference Systems are synonymous with "Datum" in legacy industry usage, although there is not quite a one-to-one relationship. A geodetic datum can be associated with more than a single Geographic CRS (or GeogCRS)

Projected Coordinate Reference Systems (or ProjCRS) are often called "Projections" in legacy industry usage, but projection is really the underlying mathematics, as opposed to its realization on a given datum. In EPSG usage a Projected CRS is the coupling of a "projection" with a "geodetic datum".   This terminology has been adopted by the international Open GIS Consortium and is now used globally – but not in all software packages.



Just because everyone understands datums and projections does not always mean that we get it right.

The 'hand-off' between departments has to be as strictly controlled as the internal works of each department.

Case Study: Peru coordinate database problems

Use of Photo Image is courtesy of Satellite Imaging Corporation

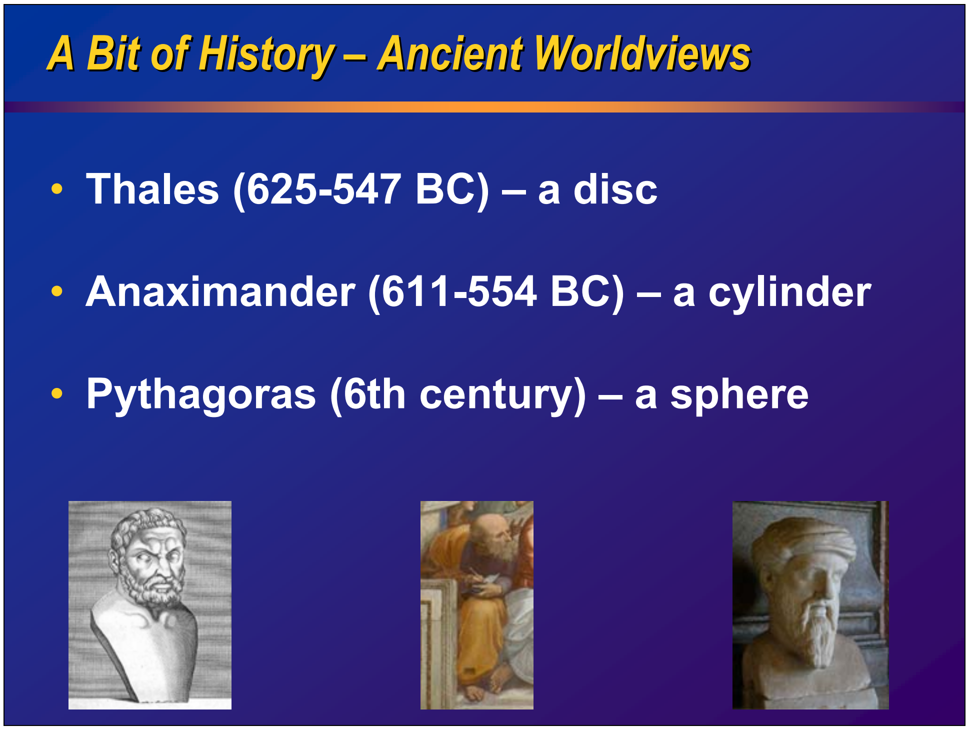
Errors of up to a kilometer or more can occur if the underlying geodesy is incorrect.

Benefits of Good Geospatial Data Management

All the previous examples translate to LOST MONEY!

- **Positional Errors of the magnitude exhibited can cause Dry Holes.**
- **One Dry Hole in the US GoM can cost many $$ Millions**

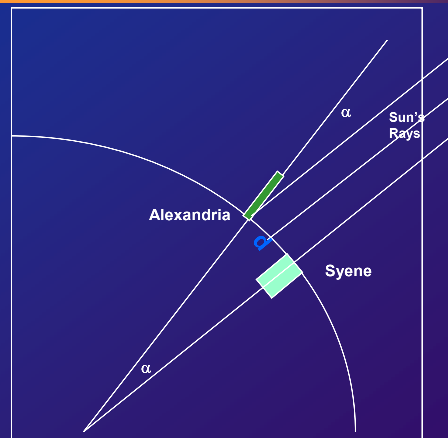
Good Spatial Data Management saves your company money!



Our knowledge of the earth's shape has progressed significantly over the centuries.

Eratosthenes: 245 BC

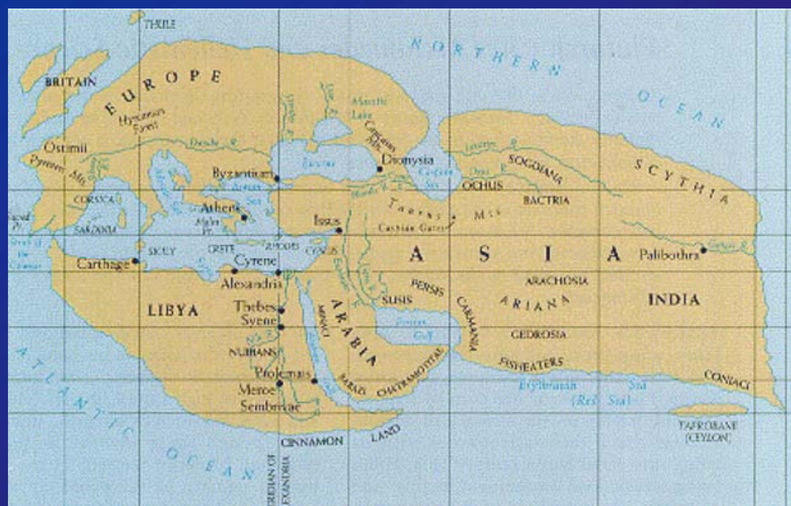
- At Syene (Tropic of Cancer), the sun's rays shone directly into well
- At Alexandria, shadow was 1/50 of a circle (about 7°)
- Eratostenes assumed the sun's rays were parallel
- The distance from Alexandria to Syene (d) 5000 stadia (1 stadia = 185.2 meters)
- Computed Earth's circumference = 250,000 stadia or about 28,750 miles
- Circumference 46,300 kms – about 15% too large



$$d:2\pi r = \alpha:360$$

An early "geodesist's" application of scientific principals and simple geometry to obtain an early estimate of the earth's size (assuming that it was a sphere)

Eratosthenes View of the World!



Just to give a perspective of the mapping knowledge in the day of Eratosthenes (245 BC)

Some Famous Individuals in Geodetic History

- **Sir Isaac Newton (1642-1727), *London***
- **Moreau de Maupertuis (1698-1759), *France***
- **Pierre Bouguer (1698-1758), *France & Peru***
- **Charles Marie de la Condamine (1701-1774), *France & Peru***
- **Johann Heinrich Lambert (1728-1777), *Germany***
- **Adrien-Marie Legendre (1752-1833), *France***
- **Pierre-Simon Laplace (1749-1827), *Paris***
- **Carl Fredrick Gauss (1777-1855), *Germany***
- **Sir George Everest (1790-1866), *England & India***
- **Alexander Ross Clarke (1828-1914), *London***
- **Guy Bomford (1899-1996), *England & India***
- **Irene Fischer *(USA, retired but still active)***

As well as: Mercator, Bessel, Airy, Hotine, Hayford, Cassini, Krüger, Snyder and many others

Biographies on each of the above scientists can be found on the internet via a simple Google search.

To assist with name identification:

•Projection methods were developed by and named after Lambert and Gauss;

•Several reference ellipsoids / spheroids were derived by Everest and Clarke

•In addition to his well known mathematical equations, Legendre studied the attraction of ellipsoids, determining that the attractions were proportional to their masses. He then introduced what we call today the Legendre functions and used these to determine, using power series, the attraction of an ellipsoid at any exterior point.

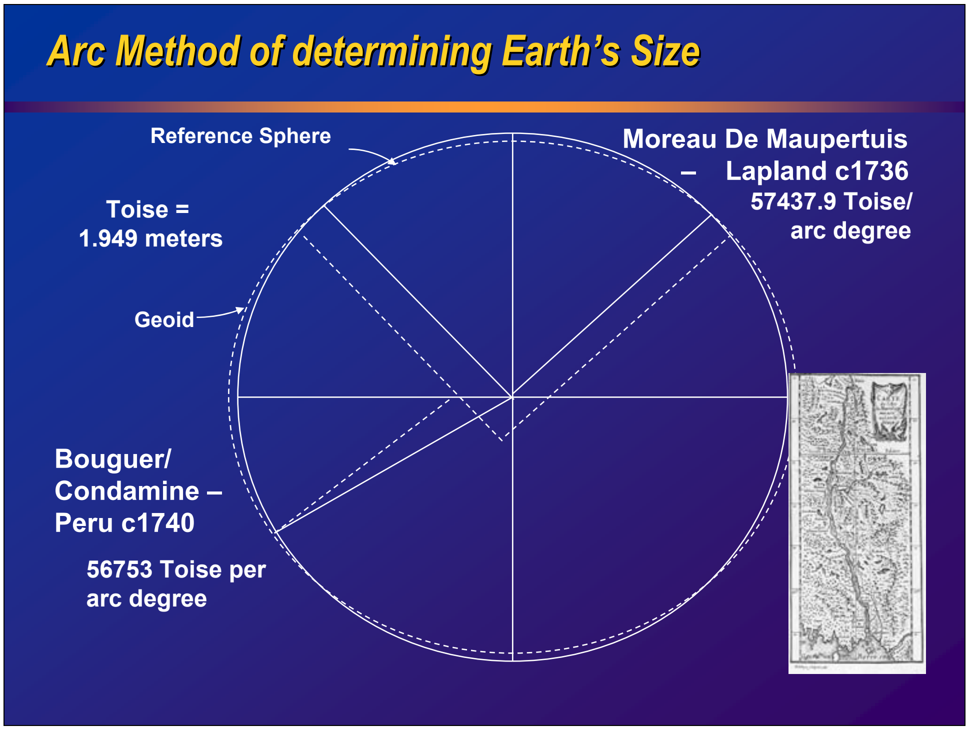
•Laplace's later years activities were devoted to presenting the law of gravitation as developed and applied by three generations of illustrious mathematicians from a single point of view. As a monument of mathematical genius applied to the celestial revolutions, the ***Mécanique céleste*** ranks second only to the ***Principia*** of Newton.

•From US NOAA historical website, http://www.history.noaa.gov/stories_tales/geod2.html: “Irene Fischer (AMS)/(DMA)* was long recognized as the U.S. expert on datums, ellipsoids and the geoid despite the fact that few results of her efforts will ever come to light, because much of her work was done under military security rules. However, anyone who ever heard Mrs. Fischer discuss these elements, among the least understood of geodetic subjects, always came away with a clearer picture of them and convinced that she indeed knew her stuff. “

•Bomford’s ***Geodesy*** (4th edition) remains the definitive reference text on Geodesy

•See the next slide for more on Bouguer, la Condamine and Maupertuis

*AMS = Army Map Service, DMA = Defense Mapping Agency (former name of the current National Geospatial Intelligence Agency (NGA)

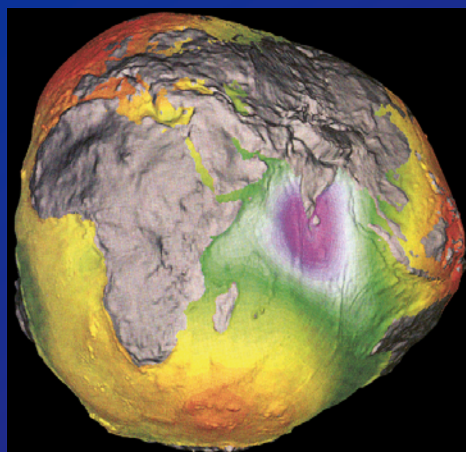


•Bouguer was a French surveyor who took part in an expedition to South America to calculate the size of a degree of latitude. He was also the first to attempt to measure the density of the Earth using the deflection of a plumb line due to the attraction of a mountain. Bouguer, together with La Condamine, made measurements in Peru in 1740 publishing his results in ***La Figure de la terre*** (1749).

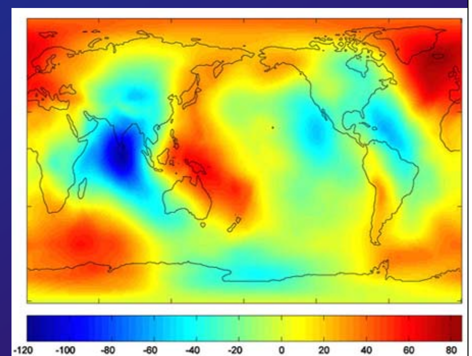
•Moreau De Maupertuis, based on prior work of Newton predicted that the Earth should be oblate, while his rival Jacques Cassini measured it astronomically to be prolate. In 1736 he acted as chief of the expedition sent by King Louis XV to Lapland to measure the length of a degree of a meridian of longitude. His results, which he published in a book detailing his procedures, essentially settled the controversy in his favor. The book included an adventure narrative of the expedition. On his return home he became a member of almost all the scientific societies of Europe.

Over 50% of the people who went on these expeditions died in the process!

Geoid vs. Ellipsoid for making maps?



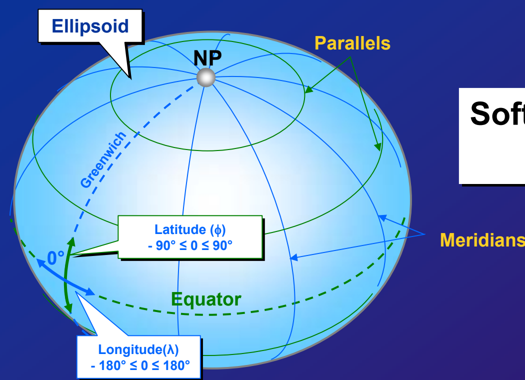
Geometric separation between reference ellipsoid and geoid is termed **geoidal undulation**



meters of separation

www.csr.utexas.edu/grace/gallery/animations/world_gravity/world_gravity_wm.html

Parallels and Meridians



Software Convention:
N,E (+); S,W (-)

Precisions are shown consistent to centimeter level

Degrees Minutes Seconds (DD MM SS.sss H)	34° 27' 17.453" N	118° 31' 32.684" E
Degrees Decimal Minutes (DD MM.mmmmm H)	34° 27. 29088' N	118° 31. 54473' E
Decimal Degrees * (DD.ddddddd H)	34.2881814° N	118.5257456° E
DMS in Sexigesimal Format (DD.MMSSssss)	34.2717453° N	118.3132684° E

* difference is about 20 kilometers (12 statute miles) if DD.MMSSsss thought in DD.ddddddd format!

These are some of the conventions that affect the use and understanding of latitude and longitude as a reference system describing location.

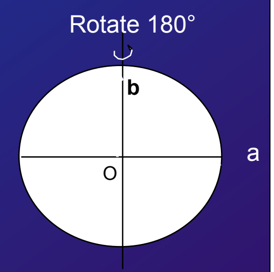
Sometimes people present DMS in a DD format called “sexigesimal”, DD.MMSSssss . Use of this can cause errors because of lack of recognition of format unless metadata makes the format clear. Such errors are usually pretty large and therefore easy to spot. Not so easy to spot with small minutes and seconds.

Formulae of the Ellipsoid

$$e^2 = \frac{(a^2 - b^2)}{a^2}$$

$$e'^2 = \frac{(a^2 - b^2)}{b^2}$$

$$f = \frac{(a - b)}{a}$$



a = semi major axis
b = semi minor axis
e = eccentricity
f = flattening

Any two parameters may be used to adequately describe the reference ellipsoid, typically “a & 1/f”, or sometimes “a & b”; less frequently “a & e^2”

Different software packages require different ellipsoid entry parameters.

Some require “a” and “1/f”. Others want “a” and “b”. Yet others ask for “a” and “e”.

Any of the combinations are valid.

The EPSG geodetic database generally stores ellipsoidal data in the “raw” form and units provided by the originator. However, “1/f” is computed for all ellipsoids (and labeled as computed if not in original description). This dataset can be downloaded without charge at www.epsg.org

Some Ellipsoids have "Evolved" as the Foot/Meter Ratio has been modified

For Example,
EVEREST 1830 [20 922 931.8 "Indian Feet" when defined]

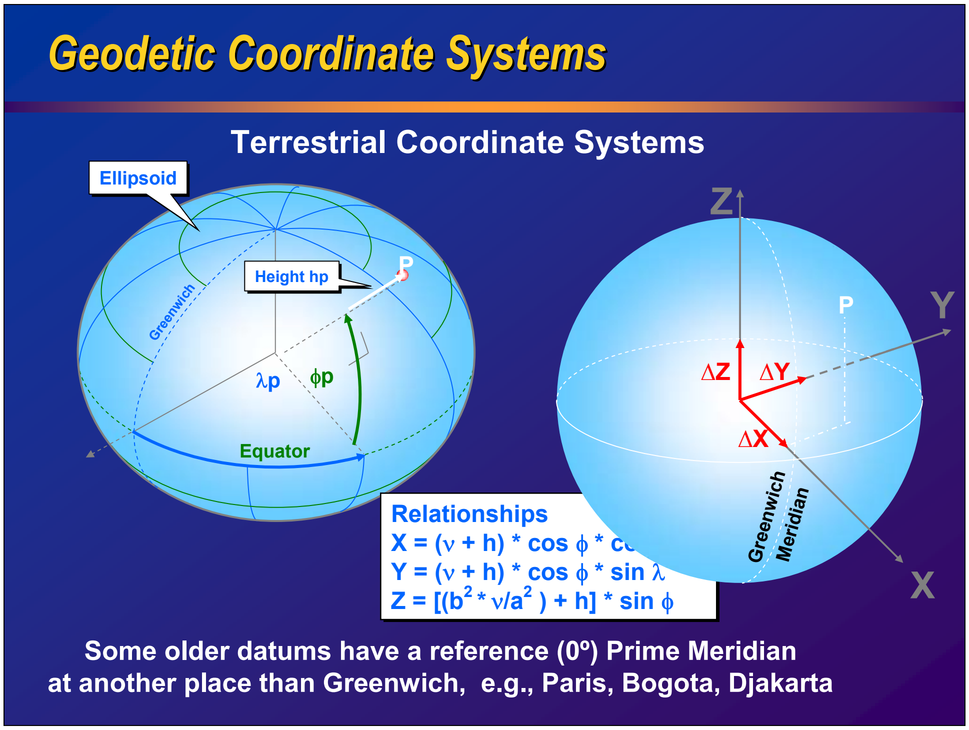
India 1937	**6 377 276.345 m**
Brunei & E. Malaysia 1967	**6 377 298.556 m**
West Malaysia 1969	**6 377 295.664 m**
W. Malaysia/Singapore 1967	**6 377 304.063 m**
(above also called "Everest Modified")	
Pakistan 1962	**6 377 301.243 m**
India 1975	**6 377 199.151 m**

This is typical of a listing of ELLIPSOID Parameters. However, these are only a fraction of the more than 70 variants in common use throughout the world.

For example, there are 5 variants of Clarke 1880, and at least 3 used, correctly or not, to define " WGS 72".

Many lists stem from those published by the old DMA organizations. They were not so concerned with the " legal " issues behind these values, but wanted a small set of values that could be used generically.

However, these, and their published datum shift values, were eagerly snapped up by software vendors as representing " the truth ".

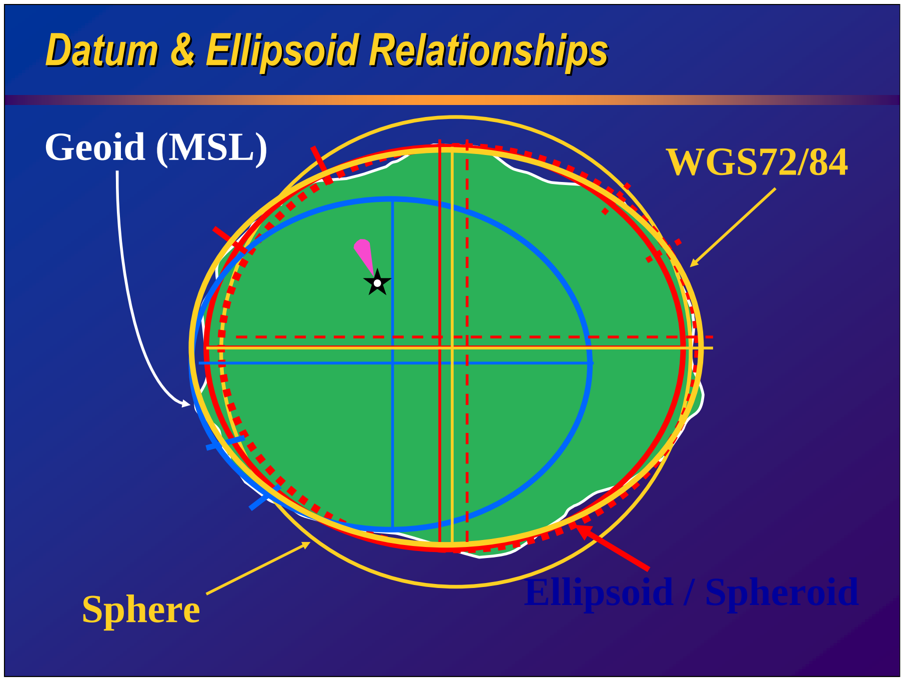


Here are two main coordinate systems used to represent three-dimensional positions on the earth – shown diagrammatically

The one is a 3D Cartesian system, represented by the X,Y,Z values on each axis of a point P on the earth. These X,Y,Z values are not the same as the X, Y and Z nomenclature used to describe easting, northing and height on a projection, and should not be confused.

Latitude is the angle measured from the equatorial plane along an ellipsoidal meridian to a place directly below or above P. Longitude is the angle measured from a reference meridian (usually Greenwich) east or west along the equatorial plane to the meridian of P. Height is the height above (usually) the reference ellipsoid of the point P. Note that since the ellipsoid and the geoid are not coincident everywhere, ellipsoidal height and elevation are not the same.

A list of all of the Prime Meridians in the ExxonMobil reference geospatial database (XOM-EPSG_v612_20070305.mdb) is given in an Appendix to this Training Manual

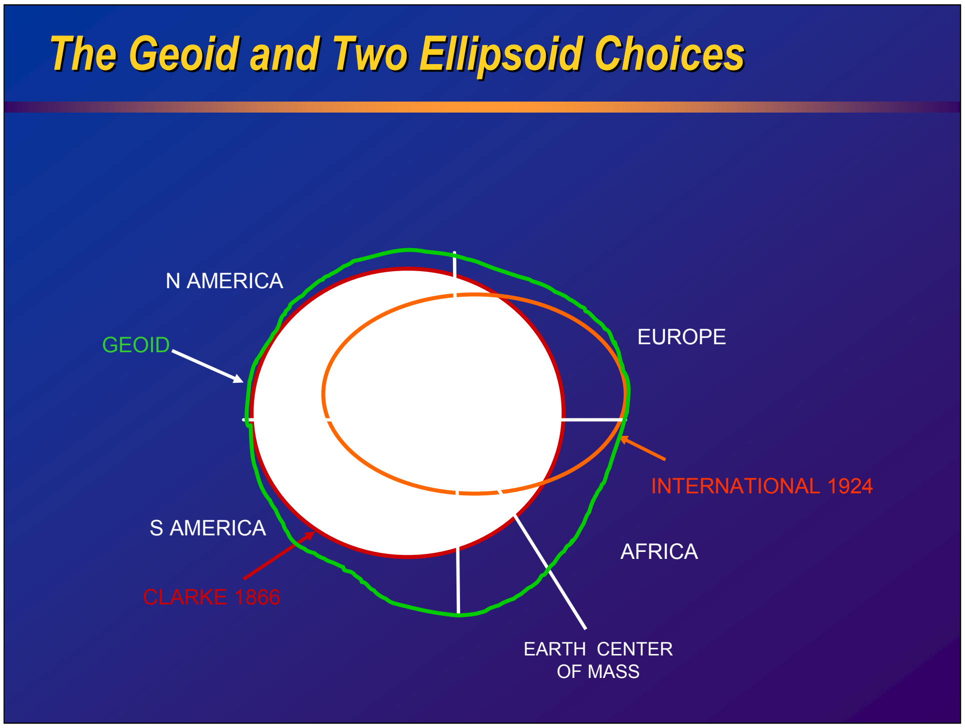


The best-fit sphere "misses" the poles by about 10 km (6 miles); the actual polar radius is much shorter than the equatorial radius.

The diagram shows differing fits of sphere and different reference ellipsoids, and the effect of using a given ellipsoid with a new datum.   Two of the illustrated datums use the same reference ellipsoid.

The center of a local-fit ellipsoid will often be far removed from the earth's center (geocenter.)

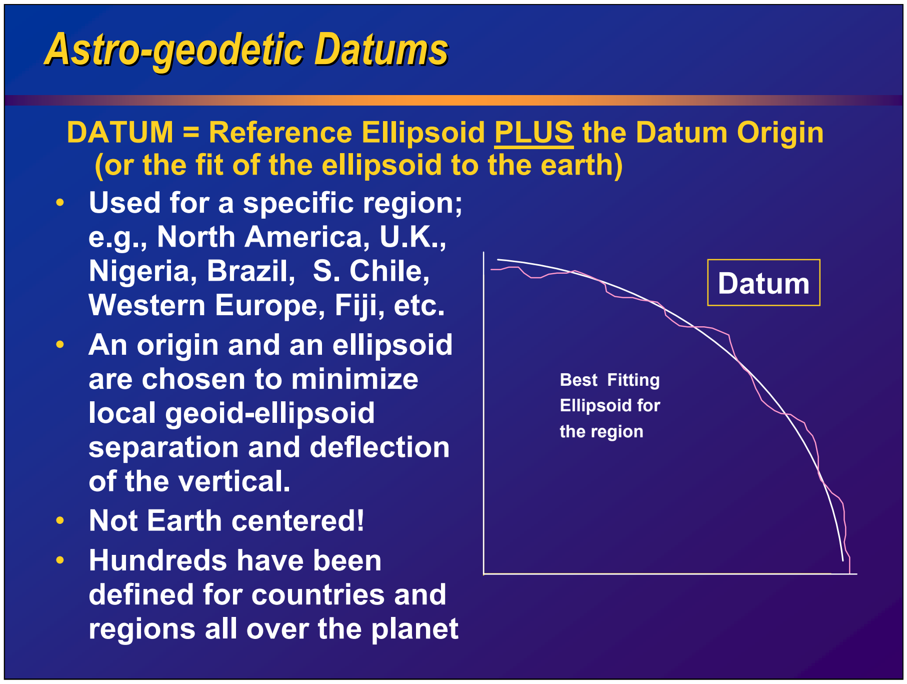
The cartographer can reference the position of a lighthouse to any of the datums shown. The resulting lighthouse positions (latitude and longitude) will differ for each of the GeogCRSs (and Datums) used to describe its position.



The differences in SPHEROIDAL shapes and sizes depend upon when and where the measurements were taken

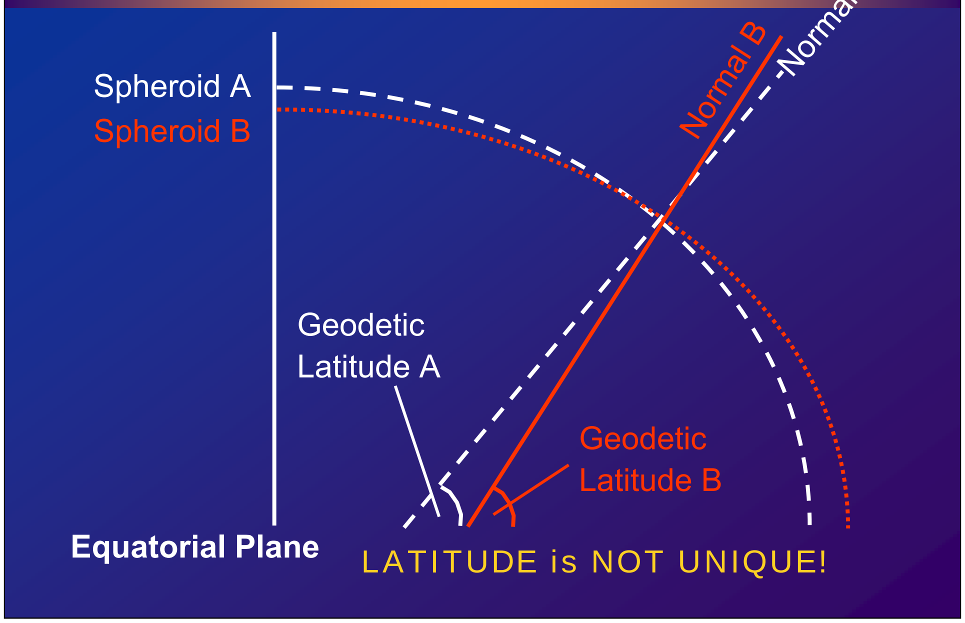
Therefore, Clarke 1880 better defines the shape of the earth in Africa than in N.America. Datums using these earth based measurements are called “Terrestrial Datums” (e.g. NAD 27, Pulkovo 1942)

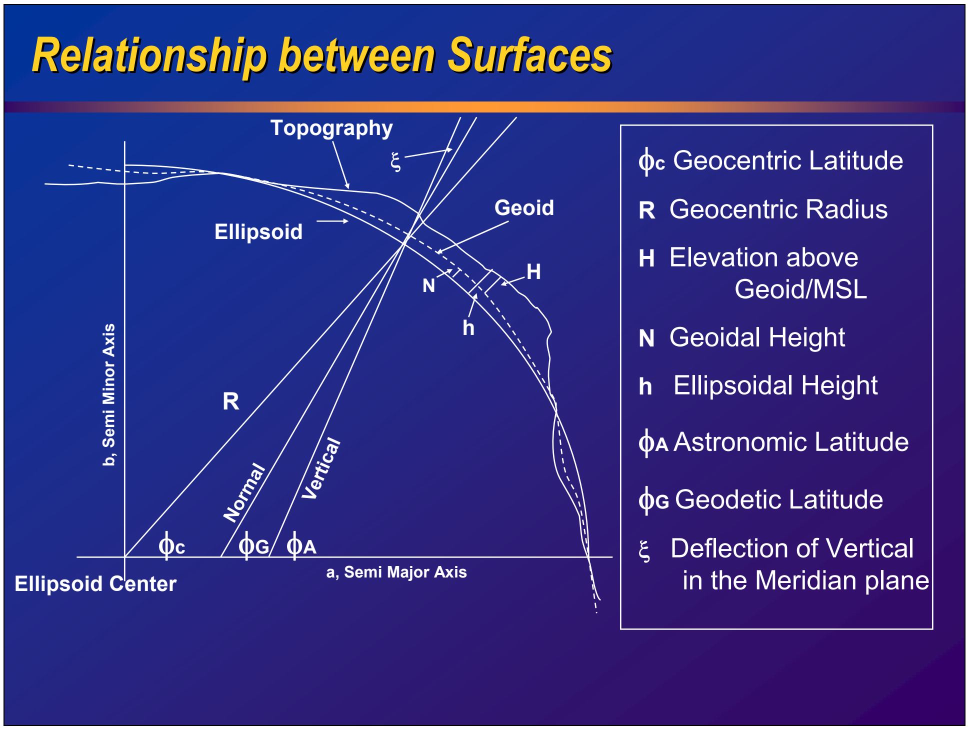
WGS 84 is the latest in a long line of SPHEROIDS that have been generated since the advent of satellites to define the shape of the earth as a whole, relative to its center of mass. This is possible as the satellite measurements are to a greater extent than on land not affected by localized gravitational anomalies. Geodetic Datums based upon satellite measurements are called “ Satellite Datums “.(e.g. many flavors of WGS 72; WGS 84).



An Astrogeodetic Datum is simply a reference Ellipsoid tied to the earth an a specific point, to best fit mapping that specific area.

Geodetic Latitude

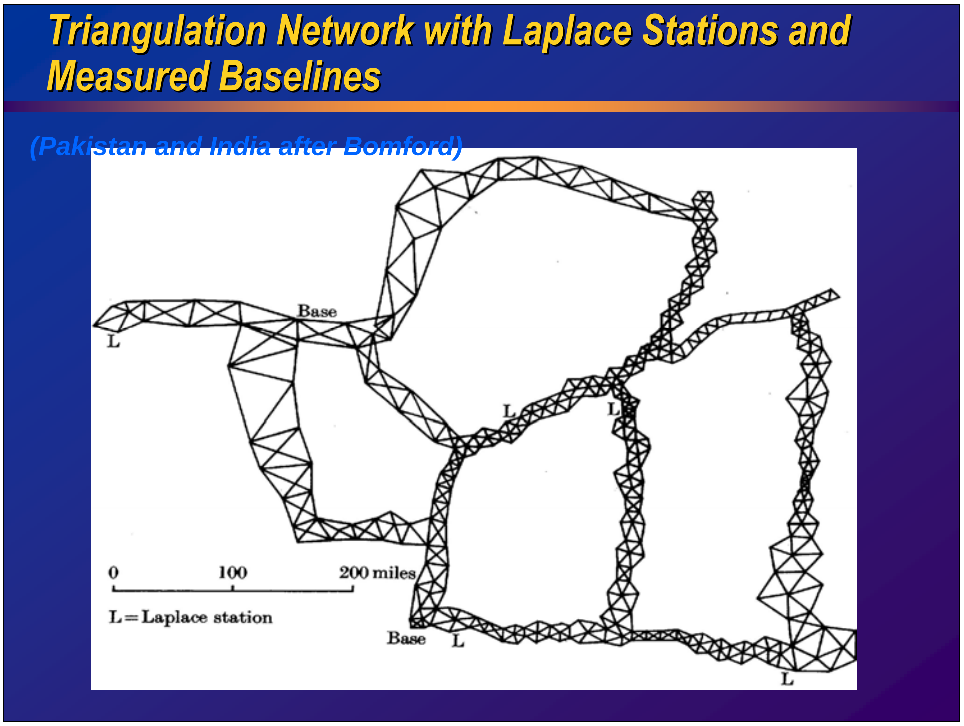




The geocentric latitude is simply a line to the center of the ellipsoid from the point.

The astronomic and geodetic latitude differ as being the normal to the geoid and ellipsoid respectively.

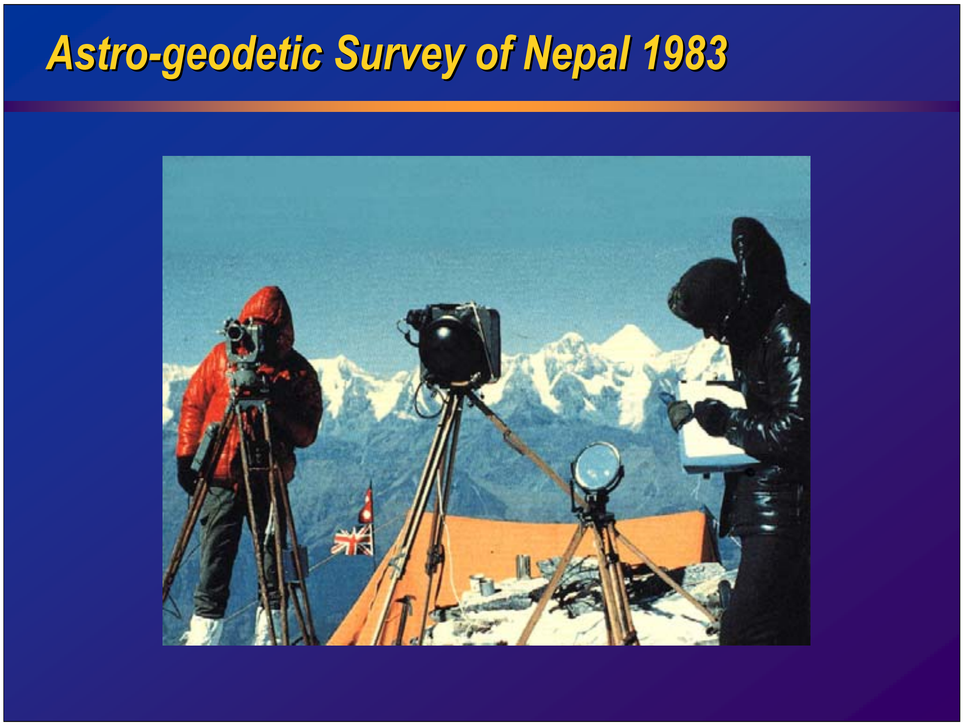
This difference in classical geodetic datums is caused by the observation instruments being referenced to local gravity. As a result, since we extend the datum using the ellipsoidal computations, we introduce error based on distance from the origin. This is adjusted out using Laplace equations and a least square error adjustment across the datum area.



This represents a section of the Geodetic Traverse used to provide base surveys of India and Pakistan.

Each Laplace station (noted by “L” symbol) represents a point on the earth's surface whose three-dimensional location (latitude, longitude and elevation) is measured with great precision (usually using dozens, if not hundreds, of observations of stars over many months). The name comes from the fact that the locations of these stations are often used to create geocentric models of the Earth via the Laplace equations.

From
http://www.warnercnr.colostate.edu/class_info/nr502/lg3/datums_coordinates/datum_type_accuracy.html,
“Once survey techniques had reached the 1960s levels of accuracy, it became clear that the only way to further improve datum accuracy was to develop more accurate models of the Earth. What wasn't immediately clear was how to do this. However, the answer had been around since the early 1800s, when the famous French mathematician Pierre Simon Laplace (1749-1827) developed what have become known as the Laplace equations. The details of these equations are far too complex to describe here, but basically what the Laplace equations do is take locational data from ***multiple*** stations (not just a single initial point) and finds the radius and flattening of a spheroid that comes as close as possible to matching up exactly with the actual surface of the Earth at all of those stations2. Almost all models of the Earth created since about 1980 are created in this way.”



This geodetic station is located in west Nepal at just over 20,000 feet

Survey equipment includes: Wild T3 theodolite, MRA5 tellurometer and heliograph. Vertical angles and measured distances are observed during the daylight and at night horizontal angles and angles to the stars

Astronomy determinations are made for determining the Astro-geodetic azimuth angle, deflection of the vertical and geoid separation

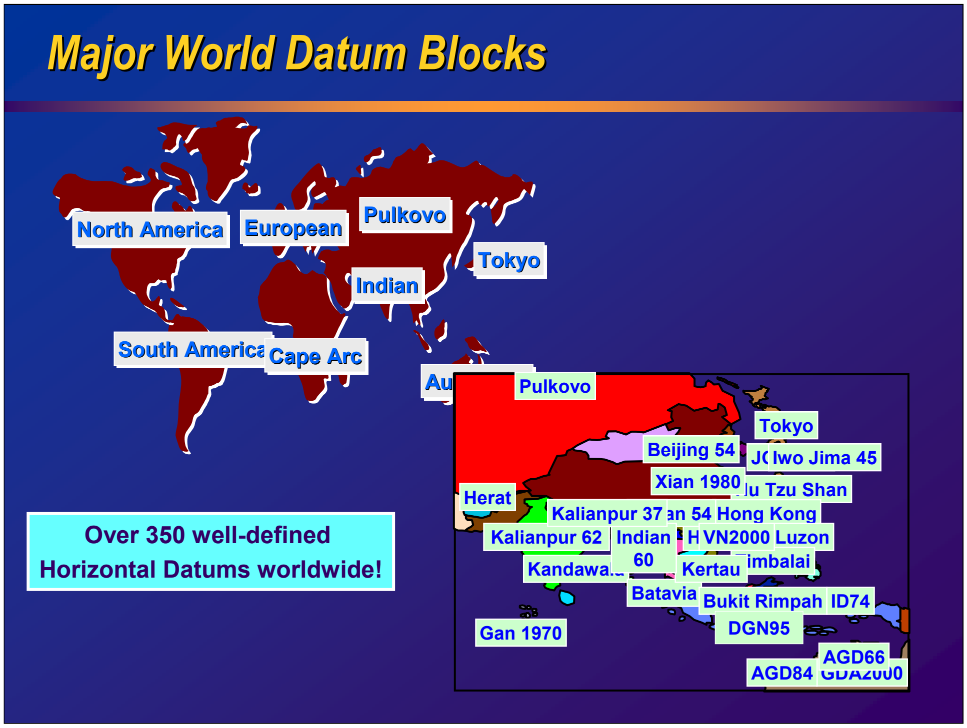
The gentleman in the red parka is Michael Barnes, who helped with the design of this course.

GeogCRS

- Geographic Coordinate Reference System (CRS) or GeogCRS
  - Result of combining a geodetic datum and a set of coordinate axes (or a coordinate system)
  - GeogCRS are often called “Datums” or “Coordinate Systems” in general traditional usage. However, upon rare occasions a Geodetic Datum may be associated with two (or more) sets of axes yielding more than one GeogCRS.

Datum Examples

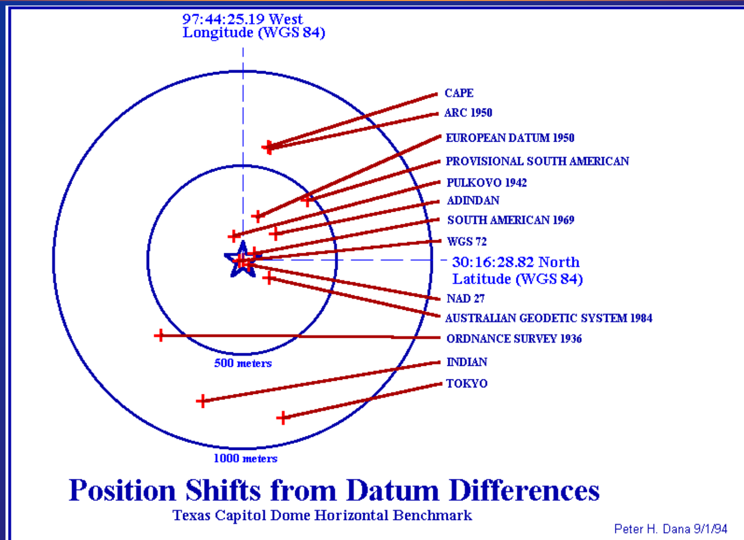
Datum Origin	PLUS	Reference Ellipsoid	=	Datum
11 main stations	+	Airy	=	OSGB36
Many points (global)	+	WGS72 ellipsoid	=	WGS72
1591+ points (global)	+	WGS84 ellipsoid	=	WGS84
Potsdam	+	International 1924	=	ED50
La Canoa, Venezuela	+	International 1924	=	PSAD56
Meade's Ranch, KS	+	Clarke 1866	=	NAD27
Many pts, North America	+	GRS80	=	NAD83
Herstmonceaux, UK	+	Airy	=	OS(SN)70
Manoca Twr, Cameroon	+	Clarke 1880 IGN	=	Manoca
Minna Station, Nigeria	+	Clarke 1880 RGS	=	Minna
Many points (global)	+	GRS80	=	ITRF yyyy
		Where yyyy is adjustment year		



Doesn’t look too bad, until you zoom in

The slide above shows the multiplicity of datums across Asia. This is illustrative only and by no means all inclusive. A number of datums used in the area are not shown.

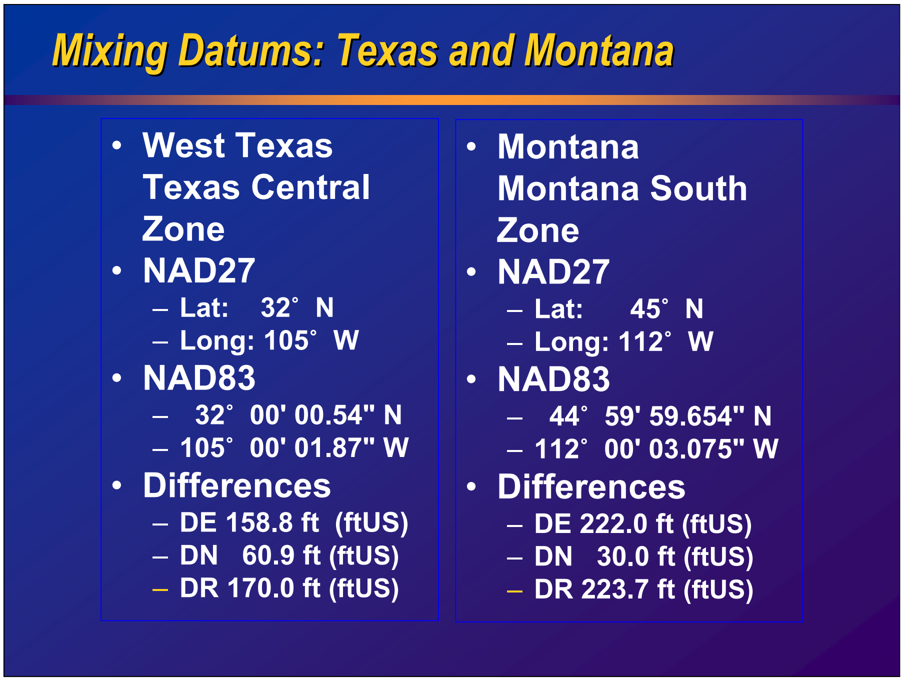
What if you get the Datum Wrong?



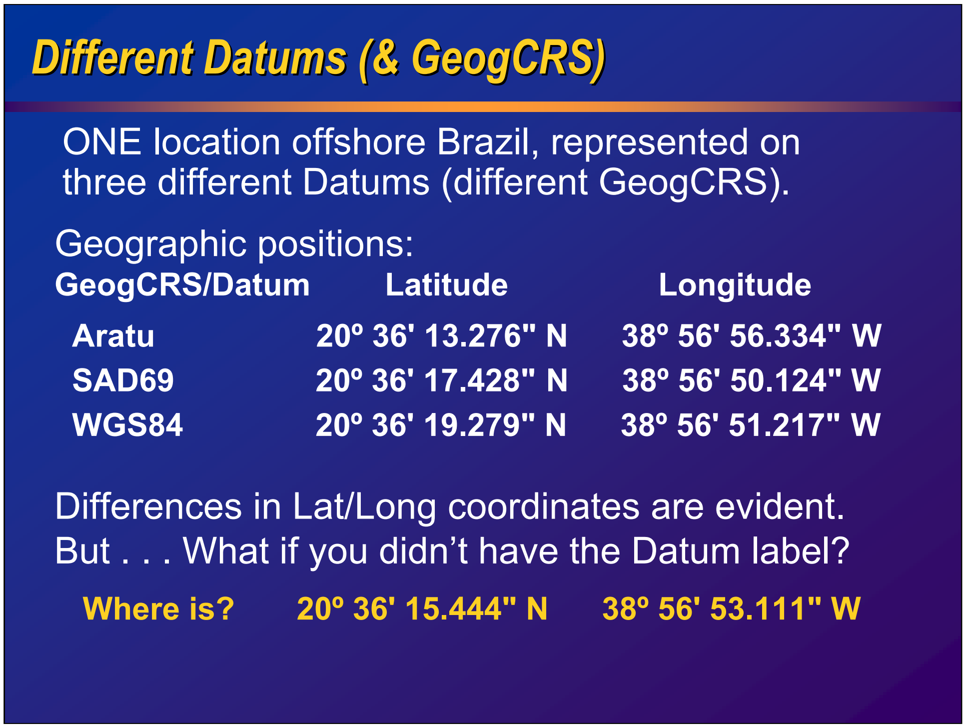
Courtesy of Peter H. Dana, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder

When does a GeogCRS differ from a Datum?

- When a *different* coordinate system (with different Axis Orientations and/or Units of Axis Measure) is used with a given datum
  - Datum: **Ancienne Triangulation Francaise**
    GeogCRS: **ATF**
    ATF has angular lat/long units in "Grads" (1/400 of a circle)
  - Datum: **Ancienne Triangulation Francaise**
    GeogCRS **(an XOM Extension): ATF (Degrees)**
    ATF modified for user convenience (XOM) to have lat/long units in degrees rather than in grads.
  - **These are NOT the same and you could be far off location if the wrong "Coordinate System" (or wrong GeogCRS) is used.**



Remember, Latitude and Longitude are not unique unless they are associated with a given geodetic Datum (and Geographic Coordinate Reference System)



Another illustration that

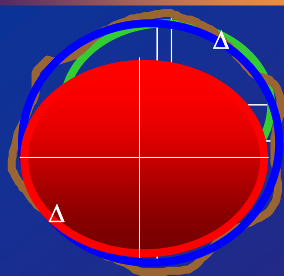
Geographic positions for a SINGLE TEST POINT offshore Brazil, represented on different Datums (different GeogCRS).

GeogCRS/Datum	Latitude	Longitude
Aratu	20º 36' 13.2757"N	38º 56' 56.3341"W
SAD69	20º 36' 17.4283"N	38º 56' 50.1240"W
WGS84	20º 36' 19.2794"N	38º 56' 51.2166"W

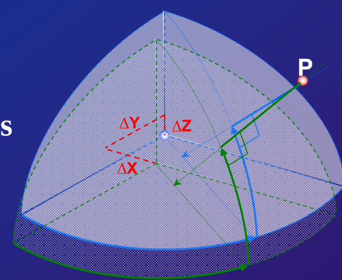
Differences in Lat/Long coordinates are evident.

But . . . . What if you didn't have the Datum label?
Where is? 20º 36' 15.444" N 38º 56' 53.111" W
Without knowing which datum, you cannot know!

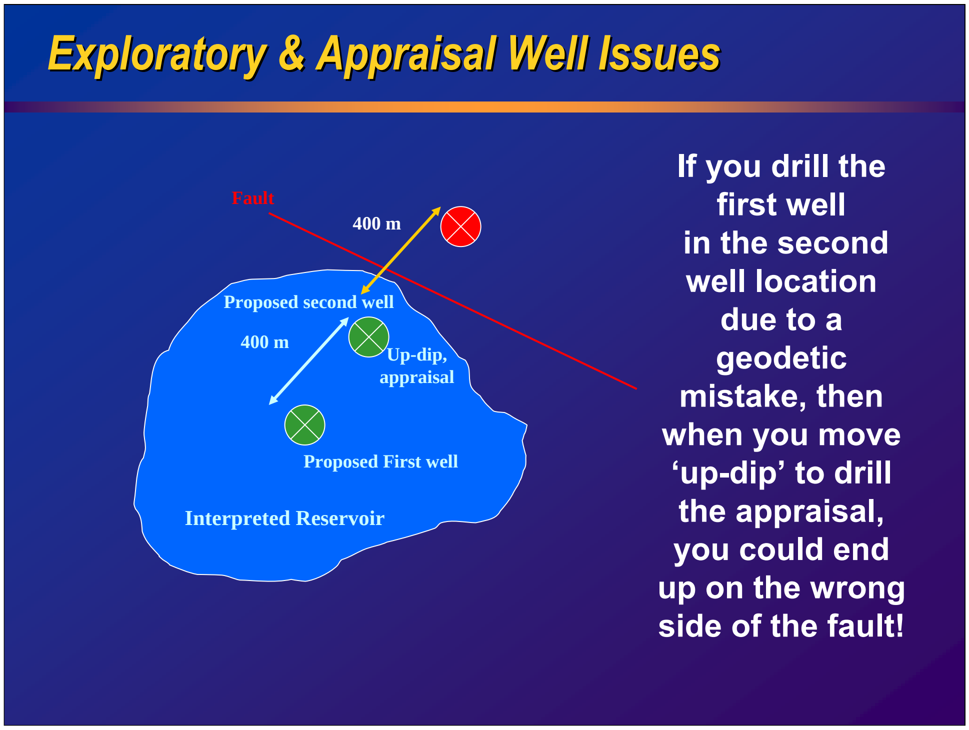
Mixing Datums: Brazil Example



Positions
for a
Single
Point



Datum	Latitude	Longitude	Local to WGS84	Local to Local
Aratu	**20º 36' 13.276"N**	**38º 56' 56.334"W**	**237 meters**	**221 meters**
SAD69	**20º 36' 17.428"N**	**38º 56' 50.124"W**	**65 meters**	
WGS84	**20º 36' 19.279"N**	**38º 56' 51.217"W**		



This has to do with timing. You do all the work

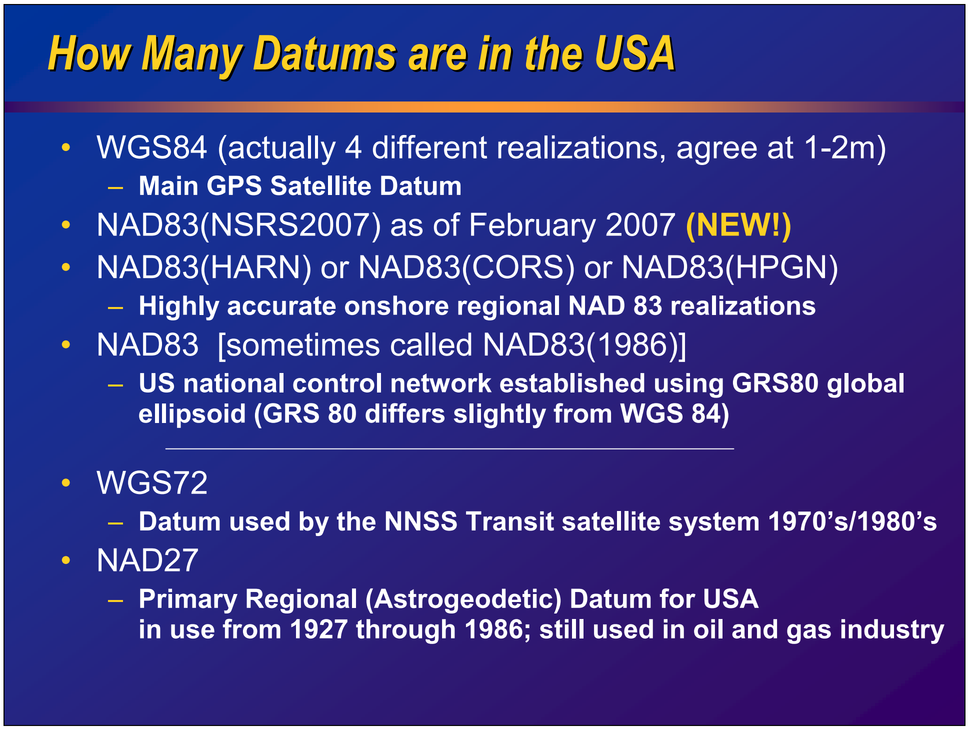
The wildcat is 'wildly' successful, so without delay – move over 400 meters to the 'sweet-spot' for appraisal and ……..Nothing shows up!!

The question is – if you have not planned and controlled the geodesy, how are you going to check this in time before the next well?

It is far better to get it right from the start with fully controlled procedures and audit trail

No-one will ever admit to this happening, but the potential cost, when the replacement of reserves is so critical to any oil and gas company market position, is possibly life threatening.

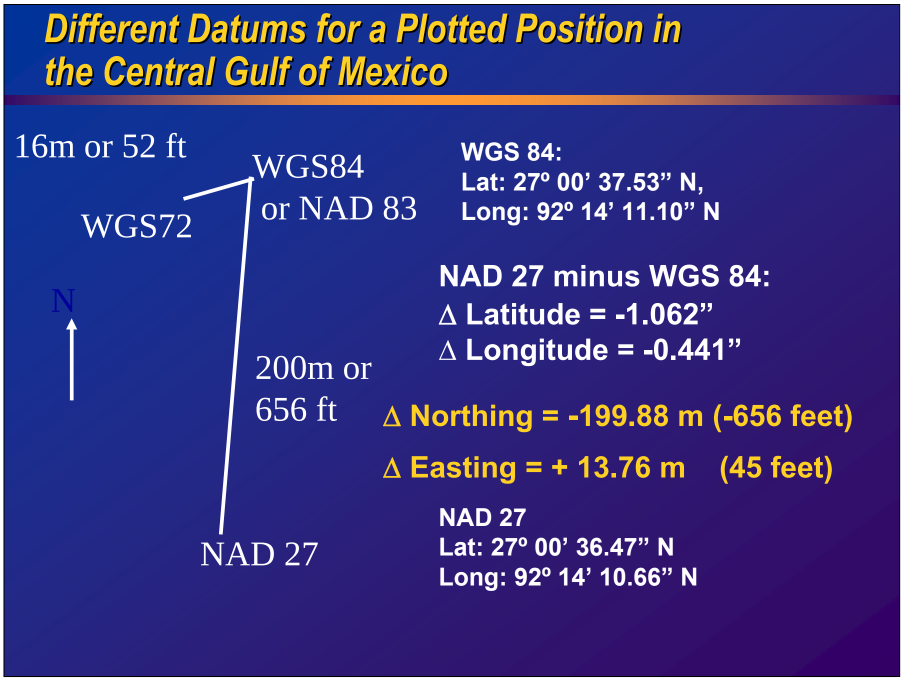
It is particularly ugly if another company comes behind and finds it!



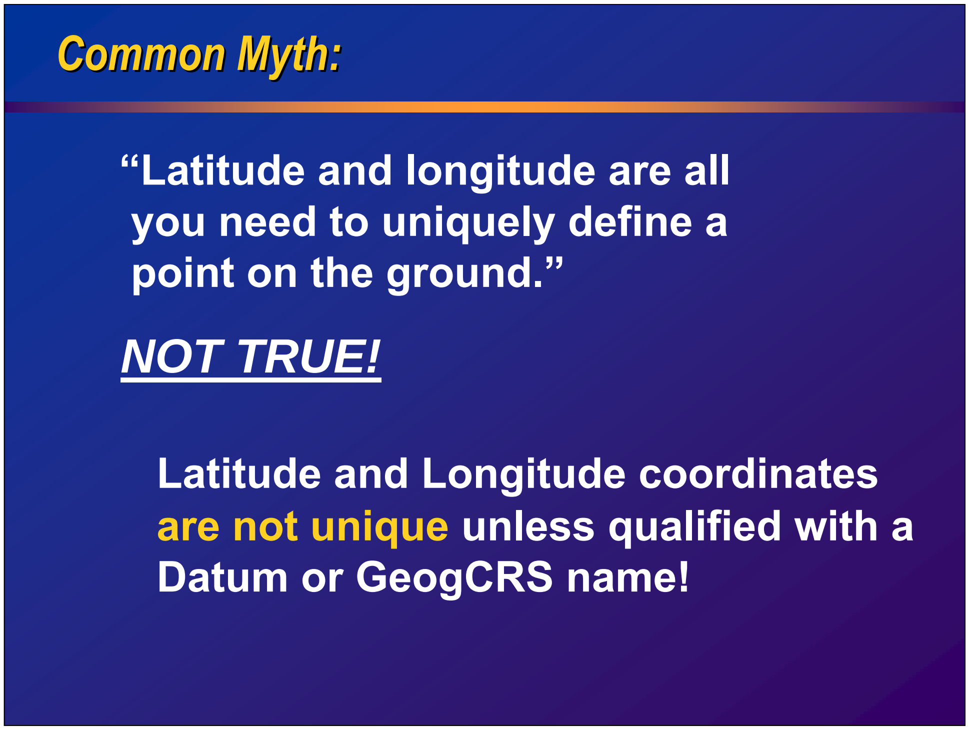
In the Domestic arena, we have to be concerned about four datums – even more for very high accuracy applications. This may be a surprise.

The good news is that the WGS84 and NAD83 datums are essentially the same, for most practical work in the oil industry – agreeing at the 1-2 meter level..

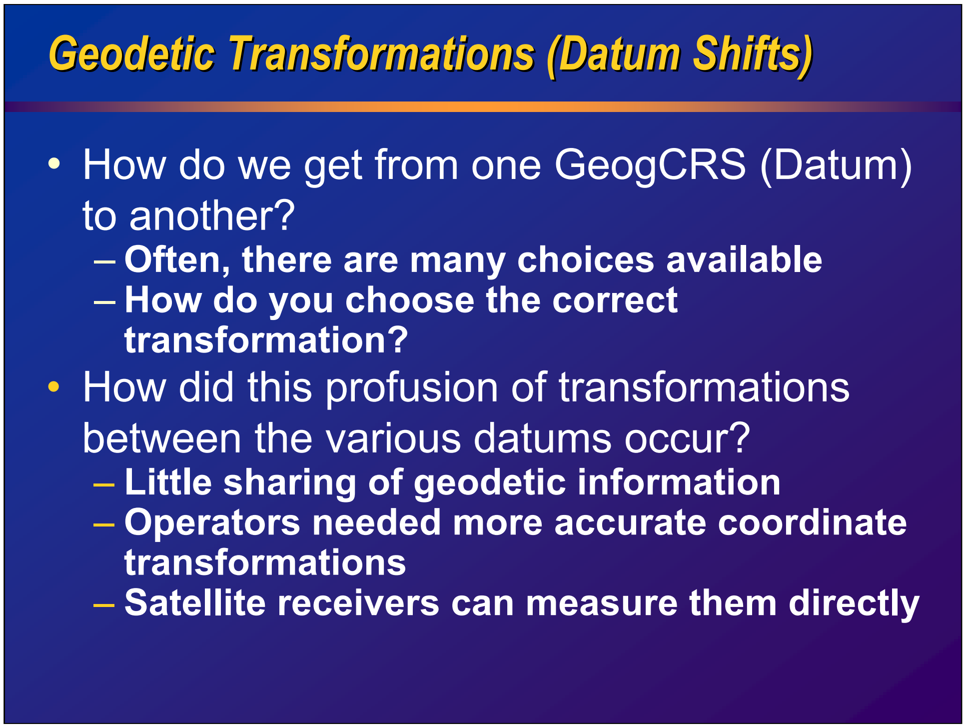
The bad news is that there is still a lot of room for mistakes as we shall see!



Typical example from US Gulf of Mexico, comparing a single location expressed in NAD27, NAD83 or WGS84 and WGS72 Geographic Coordinate Reference Systems (GeogCRS). Note that the northing difference is over 600 feet from NAD27 to any of the satellite-based datums.



This is a critical bit of knowledge!



Geodetic Transformations
(Datum Transformations)

How do we get from one Datum (CRS) to another?

We must perform a "Datum Shift" or "Transformation"

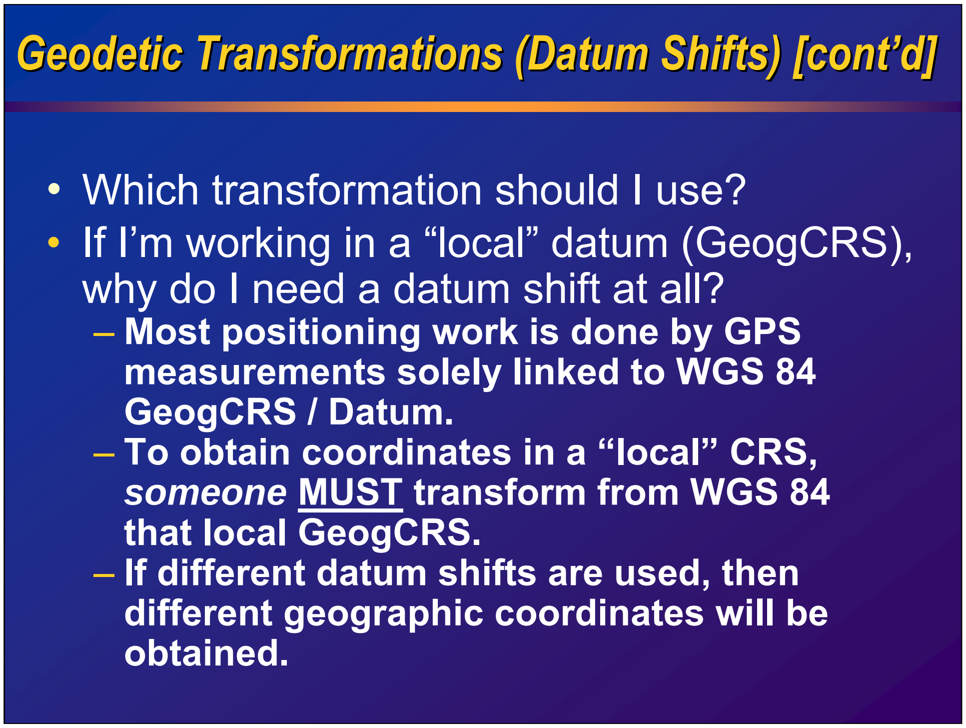
For some datum pairs there are numerous different transformations.

How did this profusion of datum transformations between the various GeogCRS occur?

Historically, there was little sharing of geodetic information. Without an "accepted" transformation,
each company evolved their own in active areas.

NIMA's published transformations were not accurate enough for many exploration and mapping activities.

Doppler Satellite receivers (and later GPS) were readily capable of directly measuring GeogCRS differences.



Geodetic Transformations
(Datum Shifts) continued

Which transformation should I use?

What has been used for related legacy data?

Is there some compelling reason to change from that?

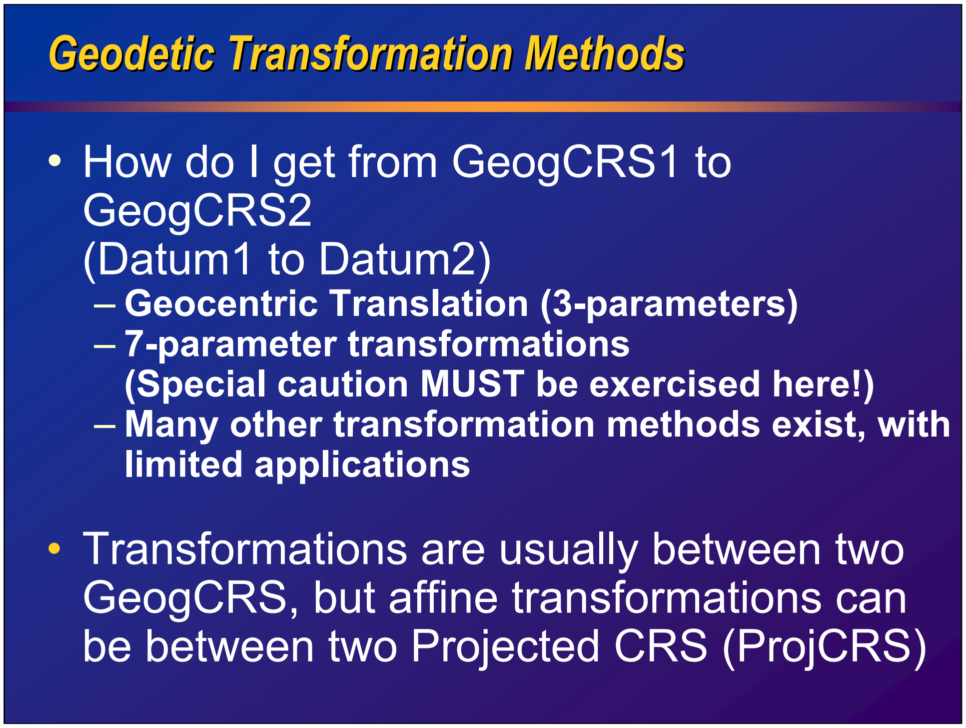
If I'm working in a "local" datum (GeogCRS), why do I need a datum shift at all?

The bulk of all positioning work in the energy sector is done via the Global Positioning System (GPS)

GPS measurements are solely linked to the WGS 84 GeogCRS (& Datum)

To obtain coordinates in a "local" reference system, someone MUST do a geodetic transformation from WGS 84 to that local GeogCRS.

If different datum shifts are used by various players, then different local coordinates will be obtained.



Geodetic Transformation Methods

How to go from Datum 1 to Datum 2
(GeogCRS 1 to GeogCRS 2.)

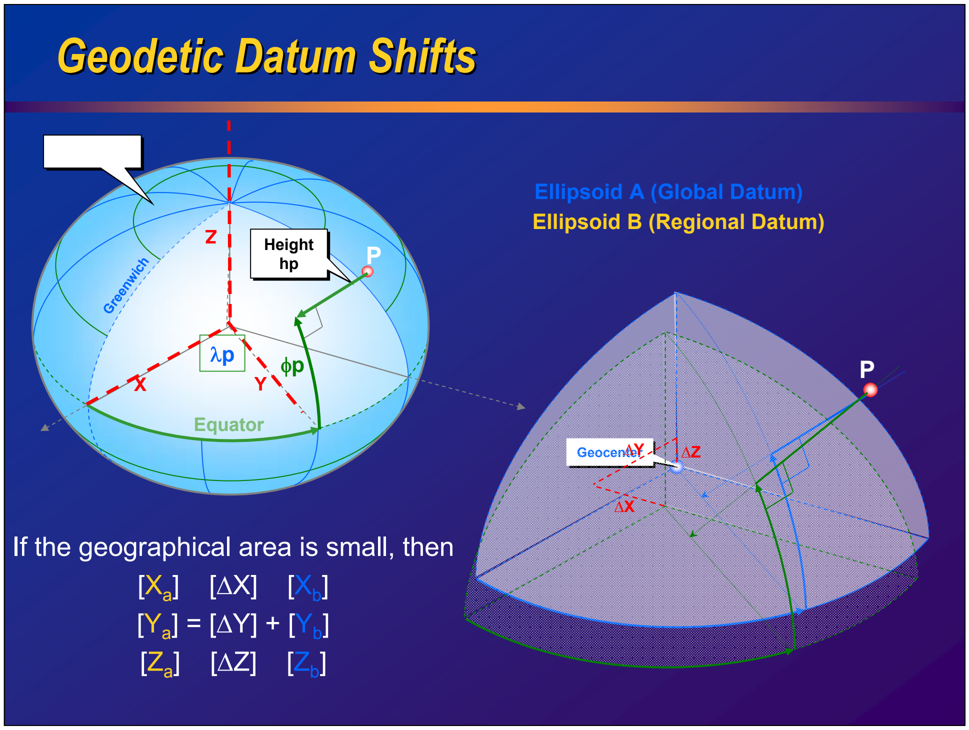
Geocentric Translation (3-parameters) is most common

7-parameter transformations are also encountered.
(A special caution MUST BE EXERCISED with these!)

Many other transformation methods exist, with limited applications (EPSG shows over a dozen, all in use)

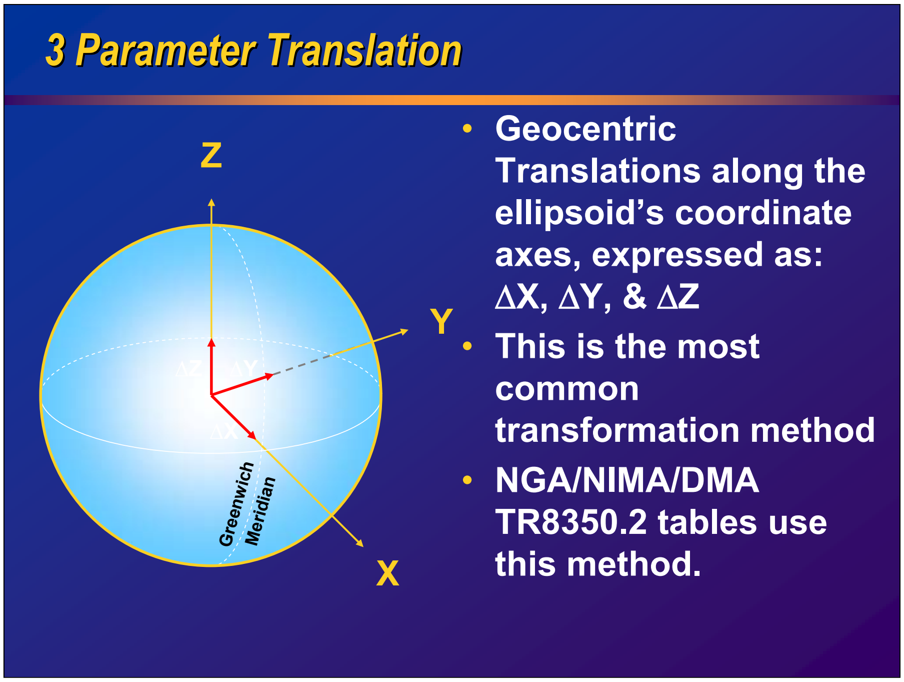
Transformations are usually between two GeogCRS, but can be between two Projected systems (ProjCRS)

This is done for work offshore Netherlands, where transformation is
from Amersfoort / RD New to ED50 / TM 5 NE by use of a complex polynomial of degree 4.



Getting from one datum to the other is conceptually simple but not well understood by the average field surveyor

or by most oil company project managers - many mapping technicians also need help



Transformation Methods in use include:

How to go from Datum 1 to Datum 2 (GeogCRS 1 to GeogCRS 2.)

Geocentric Translation (3-parameters) is most common

7-parameter transformations are also encountered. (There is a special caution associated with these!)

Many other transformation methods exist, with limited applications (EPSG shows over a dozen, all in use)

Transformations are usually between two GeogCRS, but can be between two Projected systems (ProjCRS)

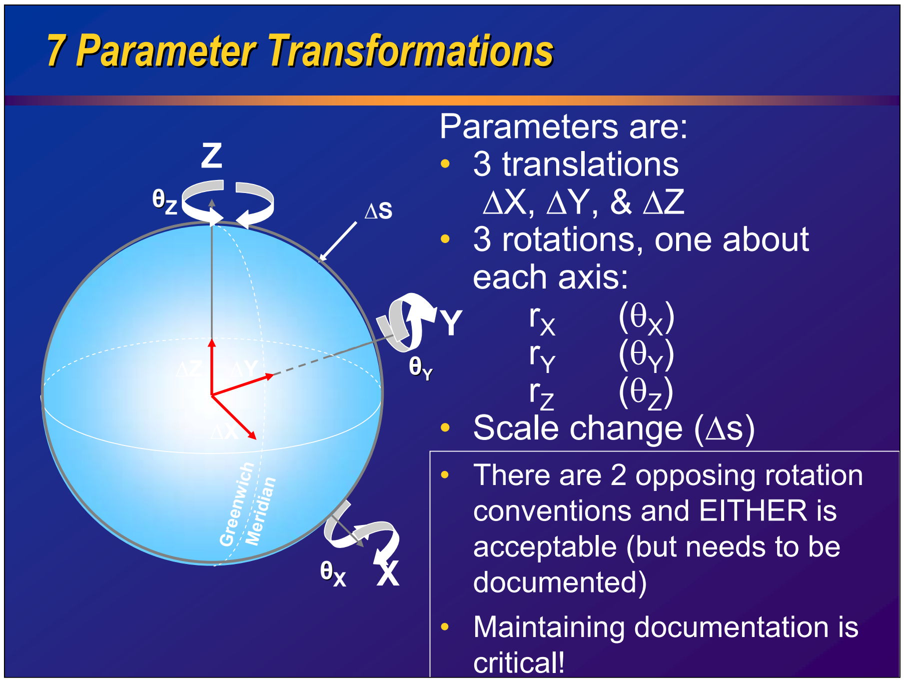
One example: offshore Netherlands, where transformation is from Amersfoort / RD New to ED50 / TM 5 NE by use of a complex polynomial of degree 4.

Simplest and most common is 3-parameter translation about center of the earth.

These **Geocentric Translations** are simple shifts along the ellipsoid's coordinate axes, expressed as:

ΔX, ΔY, & ΔZ

This is the most common datum transformation type, hence the term "datum shift." NIMA TR8350.2 gives all transformations in their tables using this method



<u>**7-parameter (and 10-parameter) Datum Transformations**</u>

7-Parameter Transformations: Parameters are:

3 translations from last slide ΔX, ΔY, & ΔZ

3 rotations, one about each of these three axes: rX, rY, rZ (or θ_X, θ_Y, θ_Z)

a scale change (or Δs) to compensate for effective earth radii in the two GeogCRS (or Datums) in the transformation area.

There are two different accepted rotation conventions for 7-parameter transformations

Position Vector 7-parameter. Transformation (used by most European entities as well as US NIMA.)

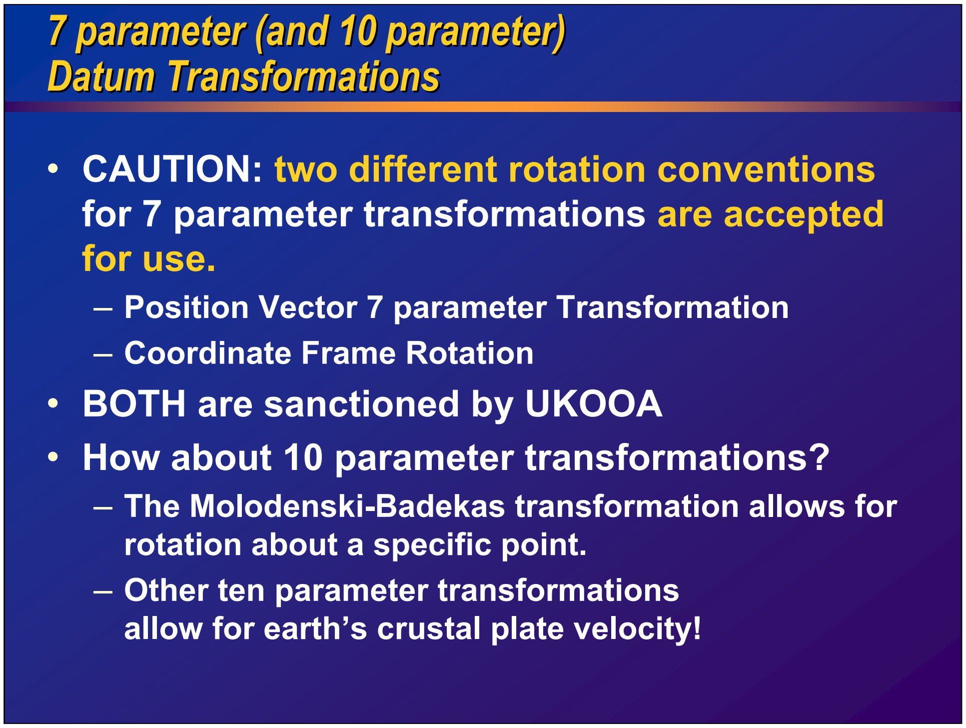
(The Position Vector transformation is sometimes called the Bursa-Wolf transformation)

Coordinate Frame Rotation (used by many US companies and US civil government agencies)

BOTH are sanctioned by UKOOA so it is important to document which is in use.

10-Parameter Transformations: Molodenski-Badekas transformation

allows for rotation about a specific point, thus needing an additional 3 parameters (coordinates of that point).



7-parameter (and 10-parameter)
Datum Transformations

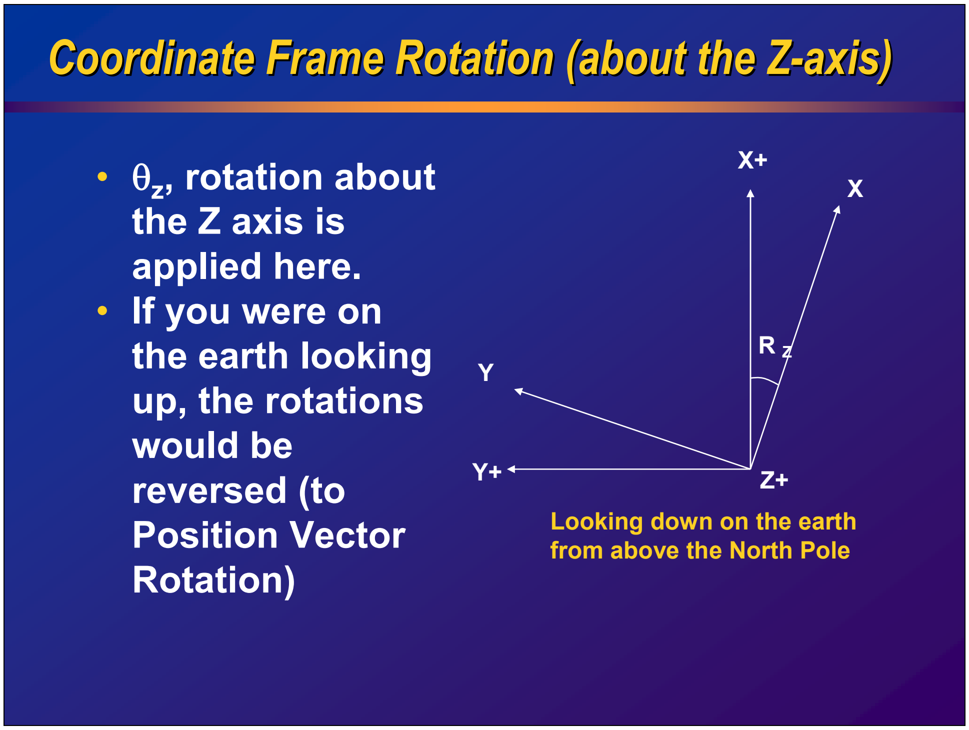
CAUTION: There are two different accepted rotation conventions for 7-parameter transformations

> Position Vector 7-parameter. Transformation (used by most European entities as well as US NIMA.)
>
> > (The Position Vector transformation is sometimes called the Bursa-Wolf transformation)
>
> Coordinate Frame Rotation (used by many US companies and US civil government agencies)

BOTH are sanctioned by UKOOA so it is important to document which is in use.

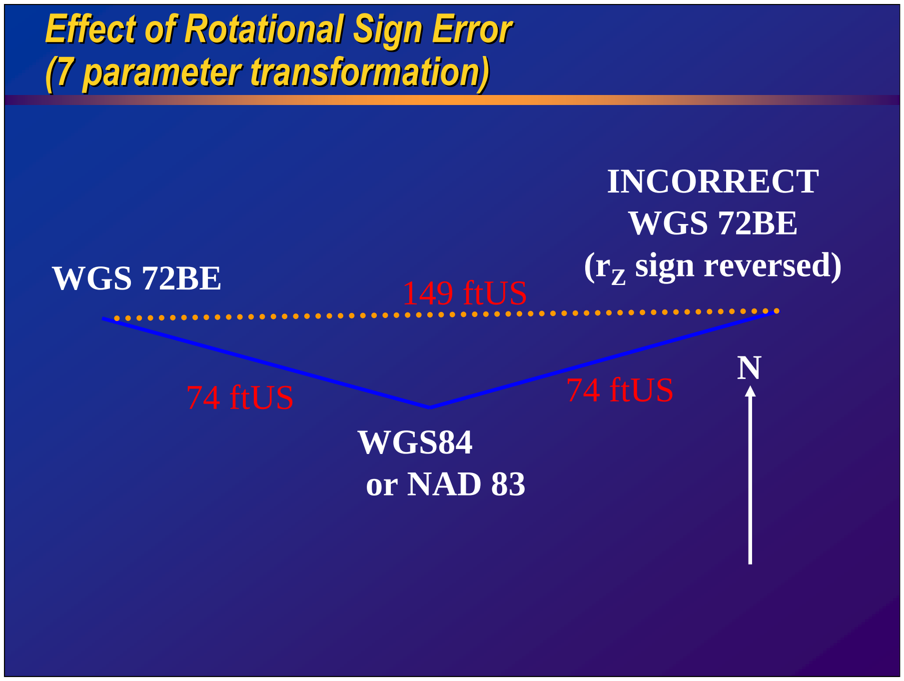
As if this was not enough!!

> The new Molodenski-Badekas transformation allows for rotation about a specific point, thus needing an additional 3 parameters.
>
> Other ten-parameter transformations allow for earth's velocity!



θz, rotation about the Z axis is applied here.

If you were on the earth looking up, the rotations would be reversed (to the Position Vector Rotation convention)

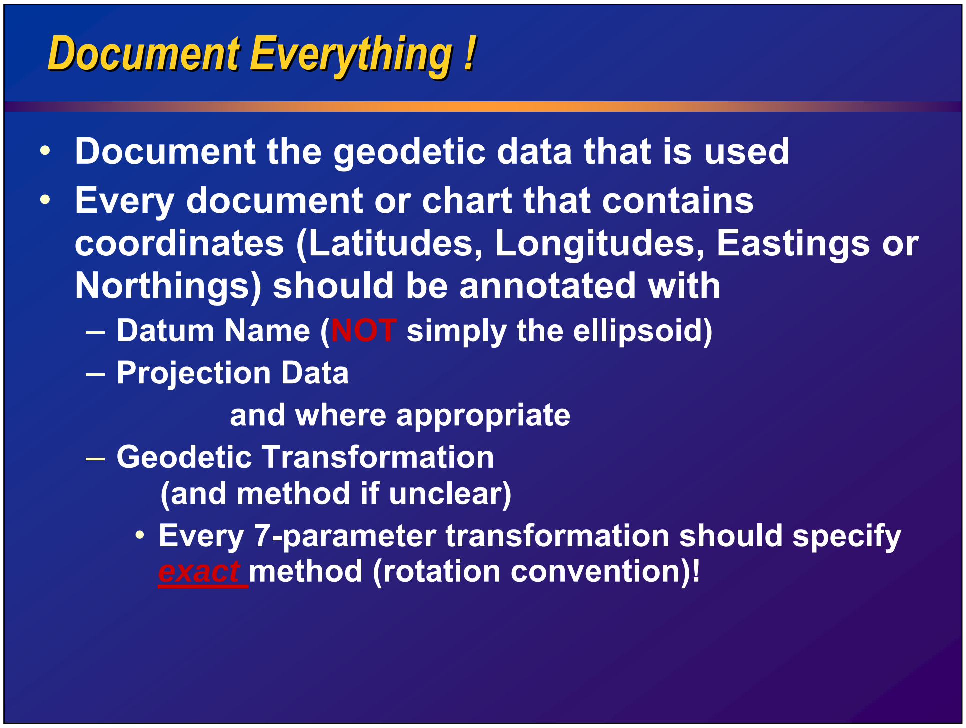


Using the incorrect 7-parameter transformation method (Position Vector 7 parameter transformation vs. Coordinate Frame Rotation) will cause the rotational parameters to be reversed, thus causing twice the error of just leaving out the term.

Even for the two similar the two global datums WGS 72BE and WGS 84, such a misapplication would generate a positional error of approximately 150 feet in the East-West direction!

Avoid Geodetic Problems

- To correctly define the coordinates of a point and provide accurate mapping, the details of the Coordinate Reference System (GeogCRS or ProjCRS) must be known and adequately documented
- Without this information, coordinates will often be misinterpreted, leading to positional inaccuracies and costly mistakes
- Geodetic Parameters are often completely ignored until after a problem has happened



Document Everything!

The best way to avoid using the wrong datum, wrong projection, or the wrong geodetic datum transformation is to document what is used.

Every document or chart that contains coordinates (Latitudes, Longitudes, Eastings or Northings) should be annotated with

Geographic Coordinate Reference System Name (Datum Name)

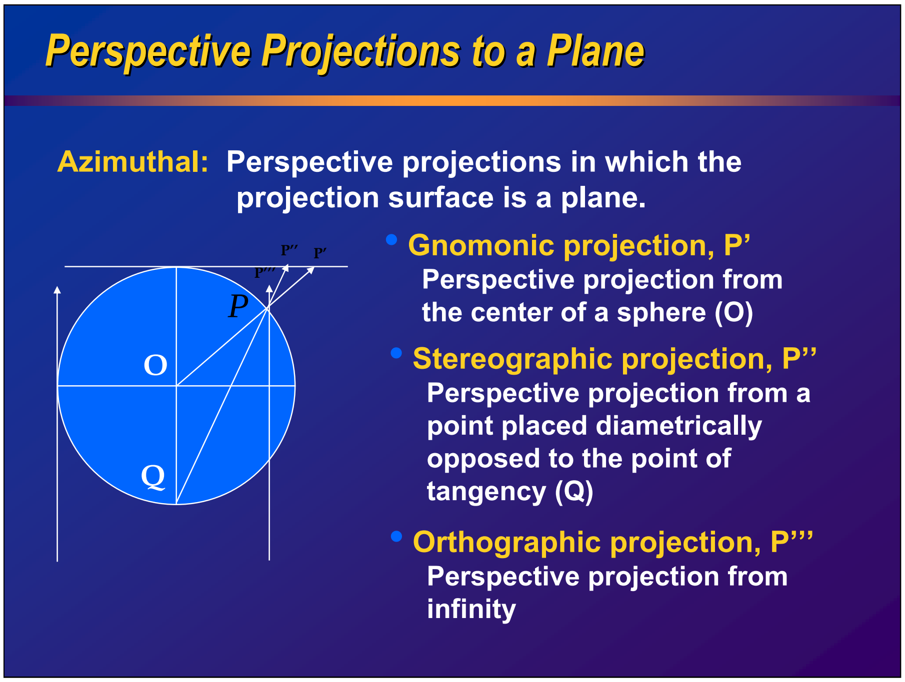
NOT simply the ellipsoid. That is insufficient!

Projection Name (with parameters if not inherent)

and where appropriate

Geodetic Transformation (and method if unclear)

Every 7-parameter transformation should specify method!



Although they are not used often, the perspective projections do occur from time to time.

The gnomonic projection is from the center of the ellipsoid, and is often used for polar regions and for small areas/harbors in oblique form.

Stereographic projection is from the point opposite the tangency. Used in its oblique form in Syria among other places. Not many software packages have this projection enabled. If you are tempted to use Lambert algorithms – don't. It will give you several hundred meters error!

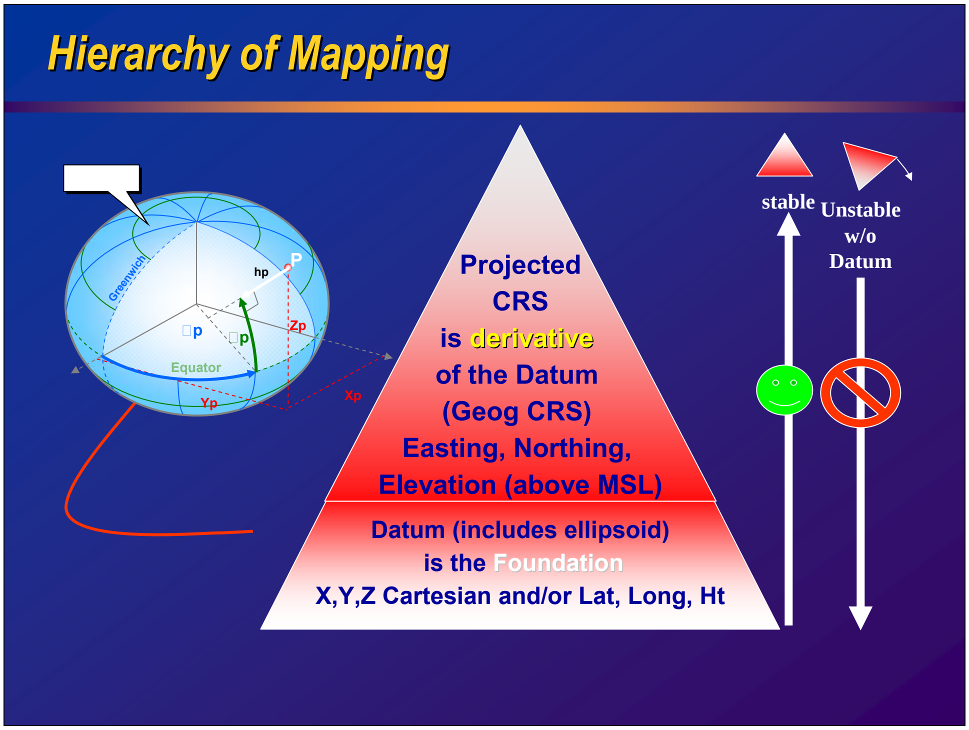
Different Projections Preserve or Distort specific Ellipsoidal Properties

- Shape and Angle **- local angles are shown correctly (e.g., all conformal projections)**
- Area **- correct earth surface area (e.g., Albers): important for mass balances and statistical information display**
- Azimuth **- all directions are shown correctly relative to the center**
- Scale **- preserved along particular lines (e.g., Equidistant)**
- Great Circles **- straight lines (Gnomonic)**

A map projection is a mathematical “mapping” of 3-dimensional spheroidal space onto a 2-dimensional planar space. Distortions are inevitable. But we can preserve selected properties of the 3-dimensional surface by our choice of mapping equations.

In this slide I’ve listed some of the desirable preservations.

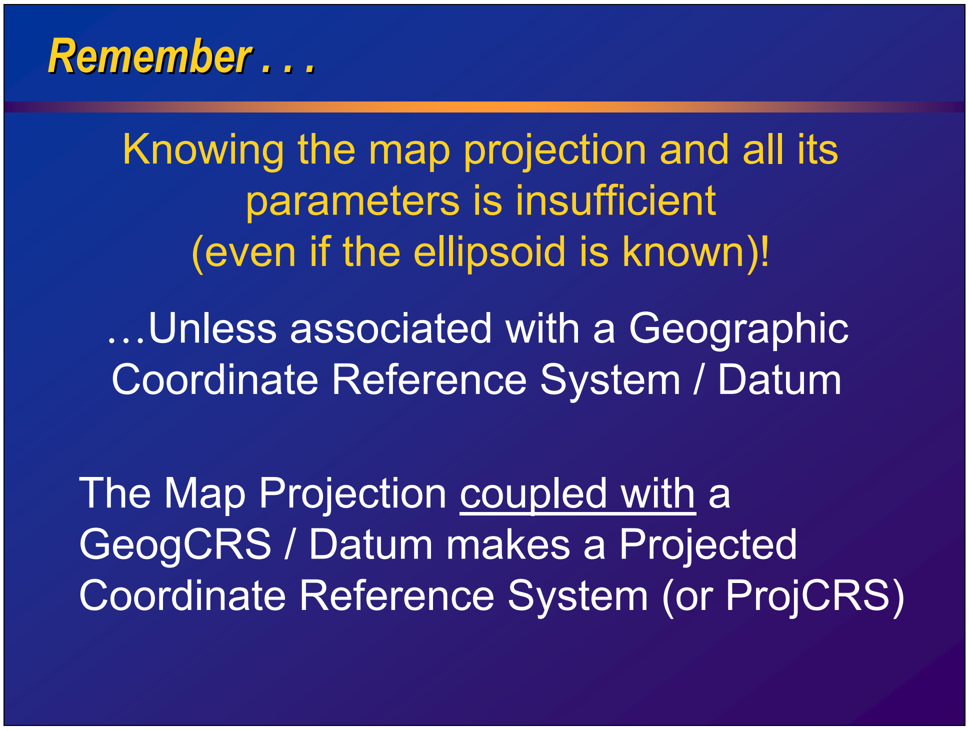
We can preserve some features, but will unavoidably distort other features.



Before getting into the details of projection science, and as a follow on to the geodesy talk, it is important to understand the hierarchy of mapping.

The basis is the Geographic Coordinate Reference System (Geodetic Datum). As you have heard, a Geog CRS is "an ellipsoid of revolution attached to the earth in some manner". If the Geog CRS is known then the ellipsoid is known as it is an integral part of the Geog CRS. The Geog CRS name is crucial, as it defines all other associated information. X,Y,Z cartesian coordinates are equivalent and interchangeable with Latitude, Longitude and Height measured in reference to the ellipsoid. The X,Y,Z nomenclature is a 3D set showing the relationship of a point to the center of the ellipsoid as it is attached for a particular Geog CRS, and has nothing at all to do with projection x,y,z (Projection CRS), which are referenced to the origin of the projection.

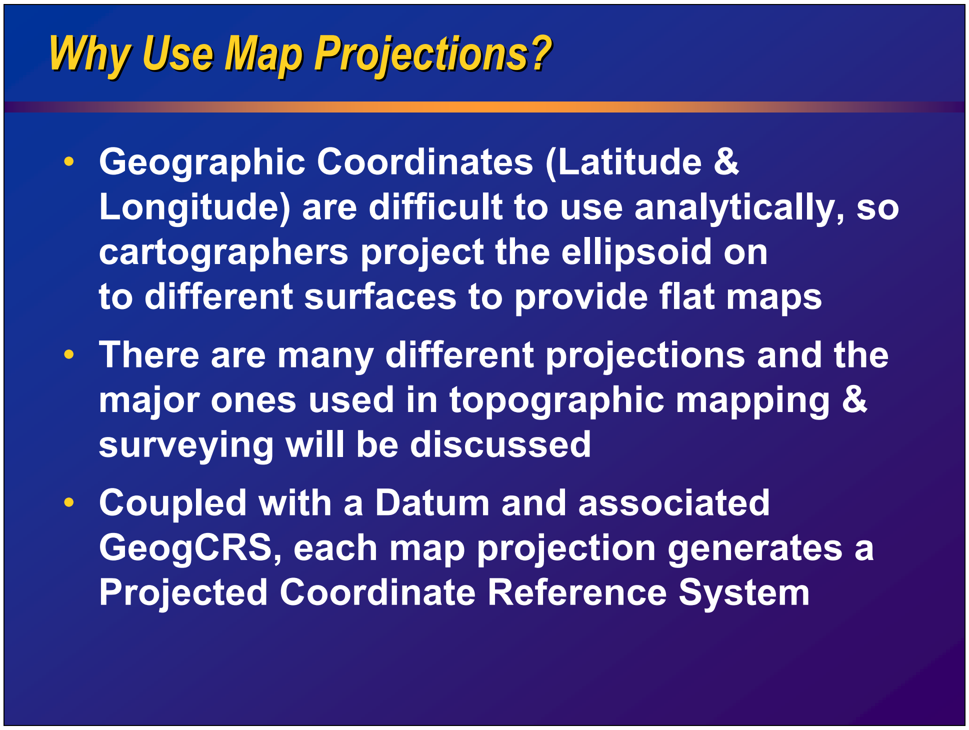
If the Geog CRS is known, coordinates can be transformed or converted from latitude, longitude and height to easting, northing and elevation (Projection CRS). If the Geog CRS is not known, it is not possible to convert, correctly, eastings and northings into latitude longitude and height or vice versa.



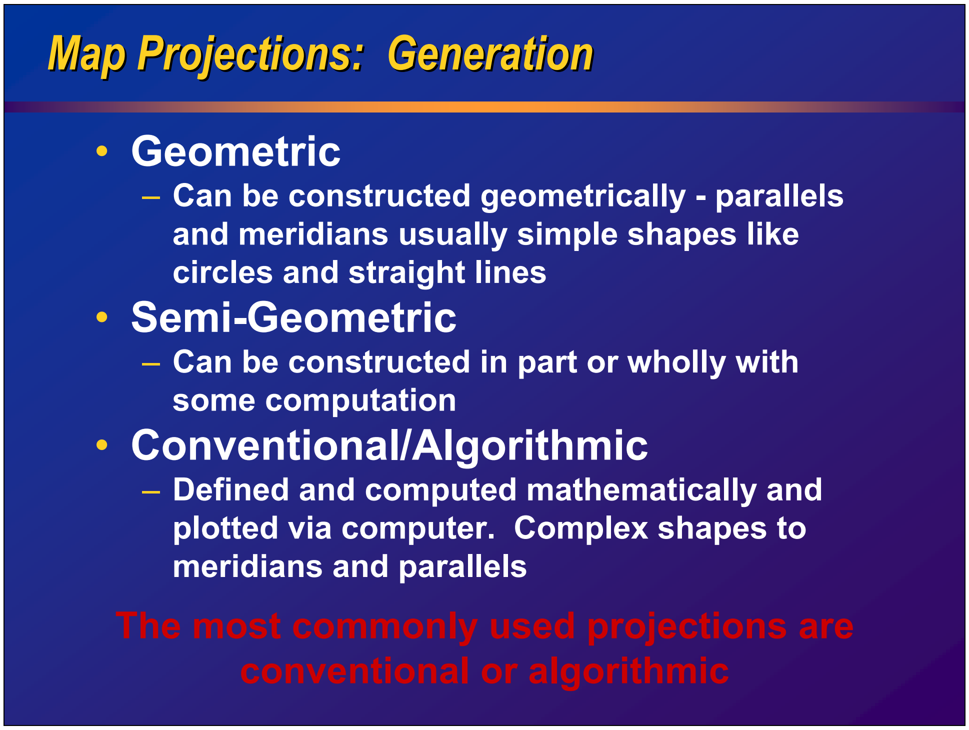
Latitudes and Longitudes in a given Geographic Coordinate Reference System (GeogCRS) and Datum can be transformed into an almost unlimited number of Map Projections (Eastings and Northings or X,Ys).

Likewise a given projection may be used in conjunction with a number of different Datums / Geographic Coordinate Reference Systems.

Often the Projected Coordinate Reference System (ProjCRS) is known only as the “Projection”, but it should always be associated with the Datum / GeogCRS.



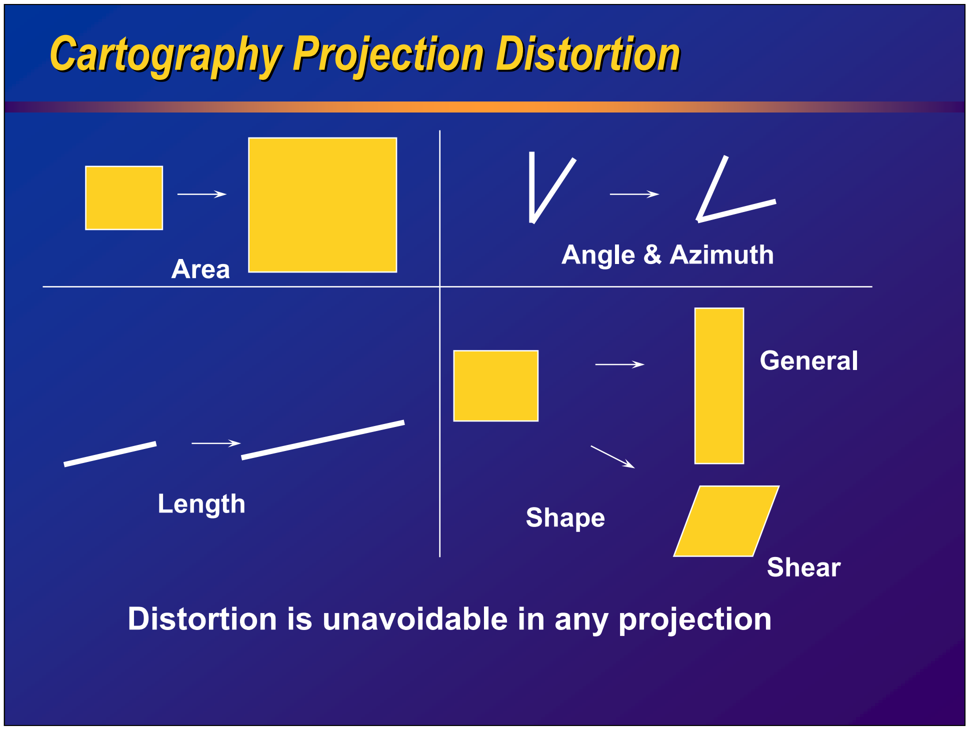
Slide is self explanatory.



Generation of Projections.

Some can be done geometrically, some by a combination of computation and others by algorithmic computation only. These are often called “conventional” projections.

The most commonly used map projections are Conventional.



Various distortions

Selection of projection depends on application. This is a complex decision and is best reached thru consultation with mapping specialist. Often decided by national datasets

Shape and Scale for different Projection Types

- Conformality (Orthomorphism)
  - Angular integrity between points is retained
  - Scale distortion at a point is independent of direction/ is the same in all directions
  - Small shapes are honored
- Equidistant
  - Scale along certain lines is true
- Equal Area
  - True area is represented, but shape and local angles are generally distorted

Introduction to some of the mapping terminology as regards types of map

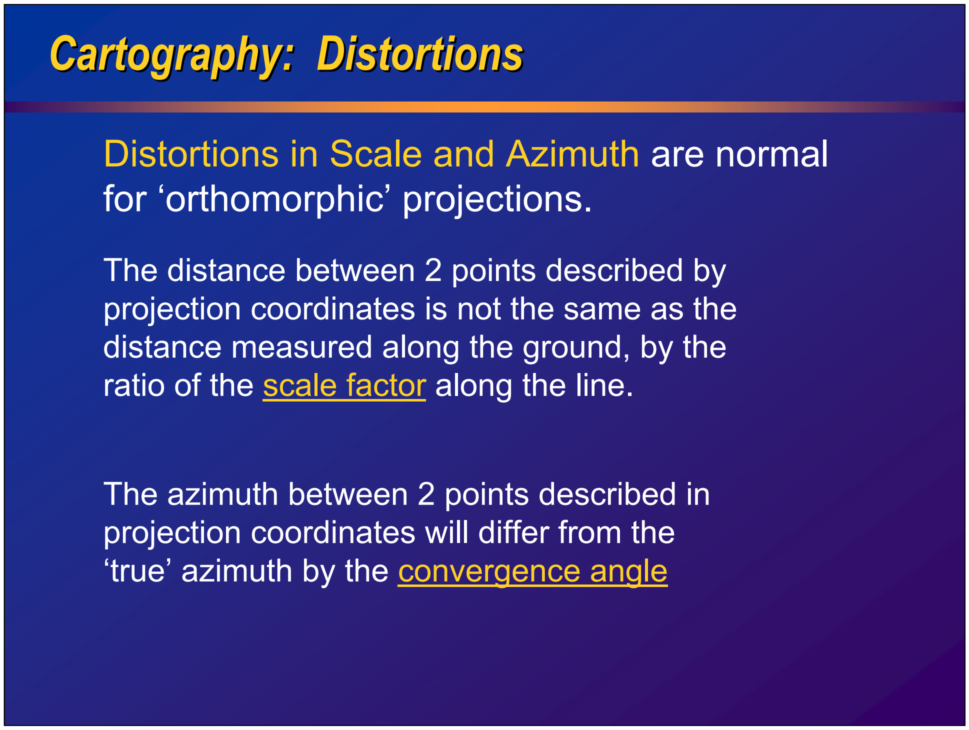
Conformal (Orthomorphic) Projections

- **Preserved**
  - Shape. **Since scale distortion at a point is the same in all directions, relatively small shapes are preserved**
  - Angle. **Angular integrity between points is retained and thus local angles are correctly shown. This is essential for angular computations on a map**
- **Distorted**
  - Linear Scale: **varies from point to point, but uniform in all directions and easily computed and compensated**
  - Azimuth: **with respect to geodetic north (convergence). Varies from point to point, but easily computed and compensated**

Conformal, or orthomorphic, projections preserve local shape. This is useful for surveyors because angles measured in the field map the same on the plane.

What we sacrifice with a conformal projection is linear scale and the orientation or azimuth of the grid. These, however, are manageable distortions because with some simple mathematics will can compute the scale and convergence at any point on the grid.

Our task, then, is to correctly apply, or compensate for, these distortions in our computations on the grid. **This is where some of the software we use goes wrong!**



On an orthomorphic projection, scale is the same in any direction at a point and angles are preserved. Reference Azimuth is not. Shape is preserved over small areas.

Measurements from the 'real world' are referenced to ellipsoid center and or true north/zero lat, zero long and MSL.

Measurements on projection are referenced to grid origin and azimuth.

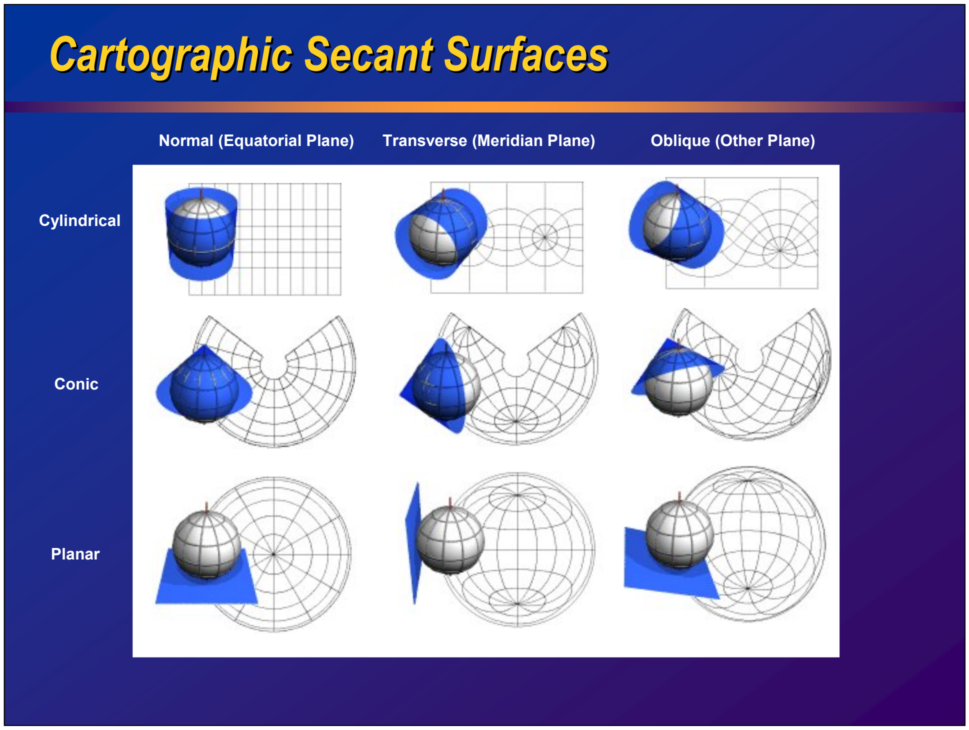
They are not the same. Planning deviated wells and other construction activities requires an understanding of these distortions or things will be misplaced.

Factors in Selecting a Map Projection

- Specific property needed on the map? (equal area, good approximations of distances and azimuths in your work area, etc.)
- Shape and size of area to be represented
- Desirability of working with same maps already in use for your area (e.g., to match concession boundaries, legal definitions, legacy data, etc.)
- The last item above is of great importance. Different groups working the same area on different maps can generate many problems.

Major Types of Projections

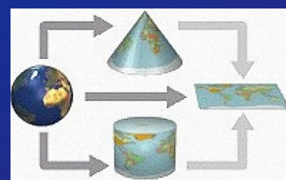
- **Conformal Projections**
  - Maintain shape. Shape on the map represents actual shape as observed on the earth
  - Ideal for surveys and topographic mapping
  - Shape is maintained at the expense of area representation. Map areas distort earth areas
- **Equal Area Projections**
  - Maintain area. Areas on the map are representative of corresponding areas
    observed on the ground
  - Ideal for displaying statistical data
  - Area is maintained at the expense of shape
    Map distances and angles may not correspond
    to actual distances and angles



Various methods of projecting data to flat surface. Cylindrical, Conic and planar. Secant vs tangent – secant allows distrbution of scale error. Transverse cylindrical touches around a meridian instead of equator. Oblique used for special applications (i.e neither polar or equatorial)

Note graphic screen presentation may allow computation of distances and azimuths in ellipsoidal domain, if the algorithm is properly managed. Users do not always understand which domain they are in. Note that on a graphic screen, the straight line joining a latitude longitude graticule across the map, will not always be the true meridian or latitude line.

Typical Map Projection Methods



- **Mercator**
- **Transverse Mercator**
- **Universal Transverse Mercator**
- **Lambert Conformal Conic**
- **Others less frequently: Stereographic, Oblique Stereographic, Oblique Mercator, et. al.**

These are the main projections used in the petroleum industry.

The others include oblique stereographic, and various equal area projections.

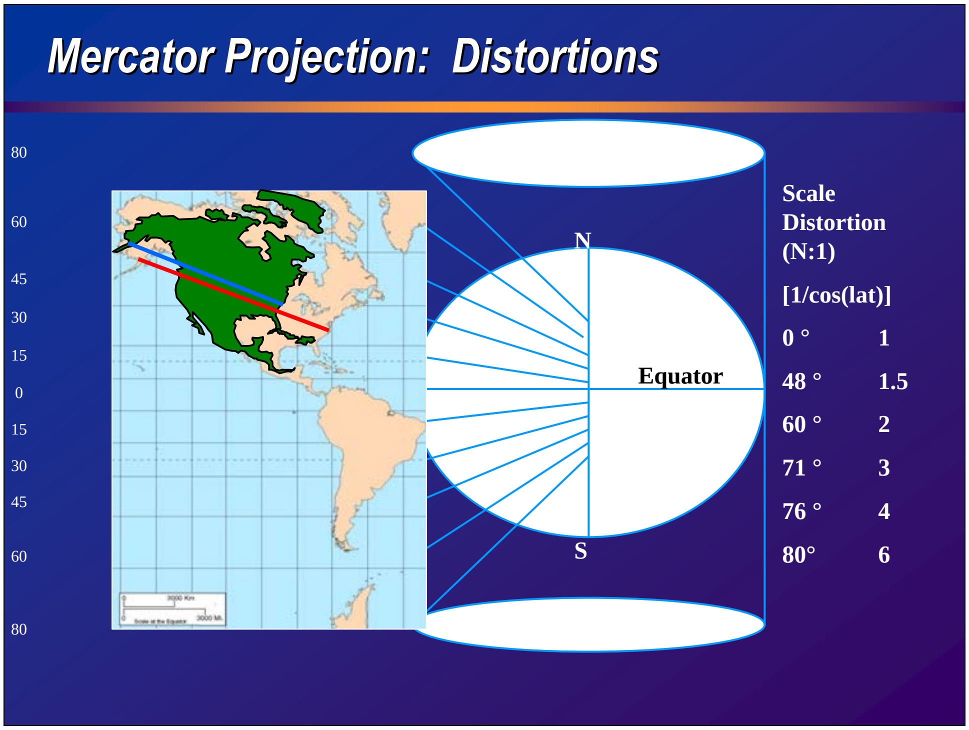
Many software packages do not deal with the less well known projections.

Cylindrical Projections (examples)

- **Mercator** (used universally in Navigation charts)
- **Transverse Mercator** (very common in survey)
  - **Universal Transverse Mercator (UTM)**
  - **Gauss Krüger**
  - **Gauss Boaga**
  - **“modified UTM with shifted C.M.” => TM CM Hh**
  - **“modified UTM in US Survey Feet” => BLM**
  - **Transverse Mercator (general case)**
- Cassini-Soldner **(*still encountered in Trinidad*)**
- Oblique Mercator
  - **Oblique Mercator**
  - **Hotine Oblique Mercator**
  - **Swiss Oblique Cylindrical**

Mercator: Projection Method

- Cylindrical
- Usually Tangent
- Orientation - Equatorial
- Conformal (Shape is okay over small area)
- Not equal area, Not constant scale, Not perspective
- Rhumb Lines become straight lines, Great Circles are curved lines
- Cannot map above 80° - i.e. cannot include poles
- Used for navigational charts



Mercator Projection. Secant of the latitude is used to project onto plane. This causes severe areal distortion in the northern latitudes, but has the property of making lines of constant azimuth straight lines – which is useful for vessel navigation.

The inset is from the Goode projection. It has its own distortions, but it shown juxtaposed with the Mercator to underscore the dramatic distortions of the Mercator projection at high latitudes.

Example: Transverse Mercator 1

Nigeria – Minna Datum & GeogCRS

- **Projection** **Nigeria West Belt TM**
- **ProjCRS** **Minna / Nigeria West Belt**

Central Meridian	**4º 30' E**
Latitude of Origin	**4º 00' N**
CSF	**0.99975**
FE	**230 738.26**
FN	**0**
Units	**Meters**

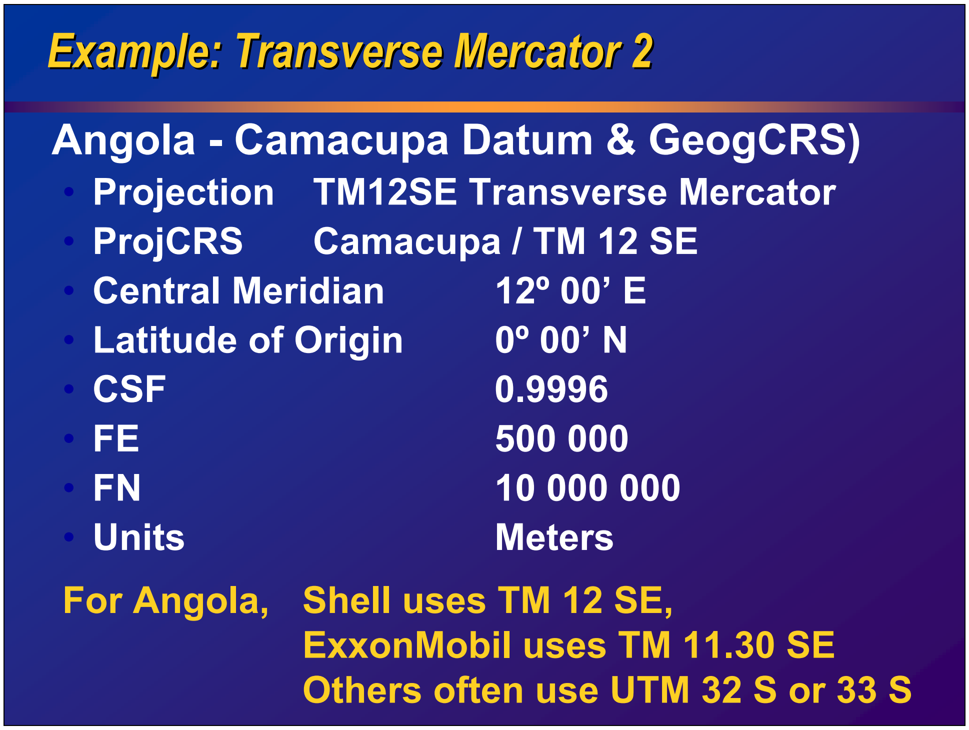
This slide shows an example of a fully qualified Transverse Mercator Projection CRS.

The false Easting and False Northing values are generally chosen to avoid having to have negative numbers. In this particular projection, it was designed before anyone wanted to work in ultra deep water, so now negative numbers occur quite frequently in the deepwater blocks

Note that the False Easting is not always a nice round number and that the latitude of the origin is not always on the equator.

These values are used by the software to compute eastings and northings from latitude and longitude or vice versa.

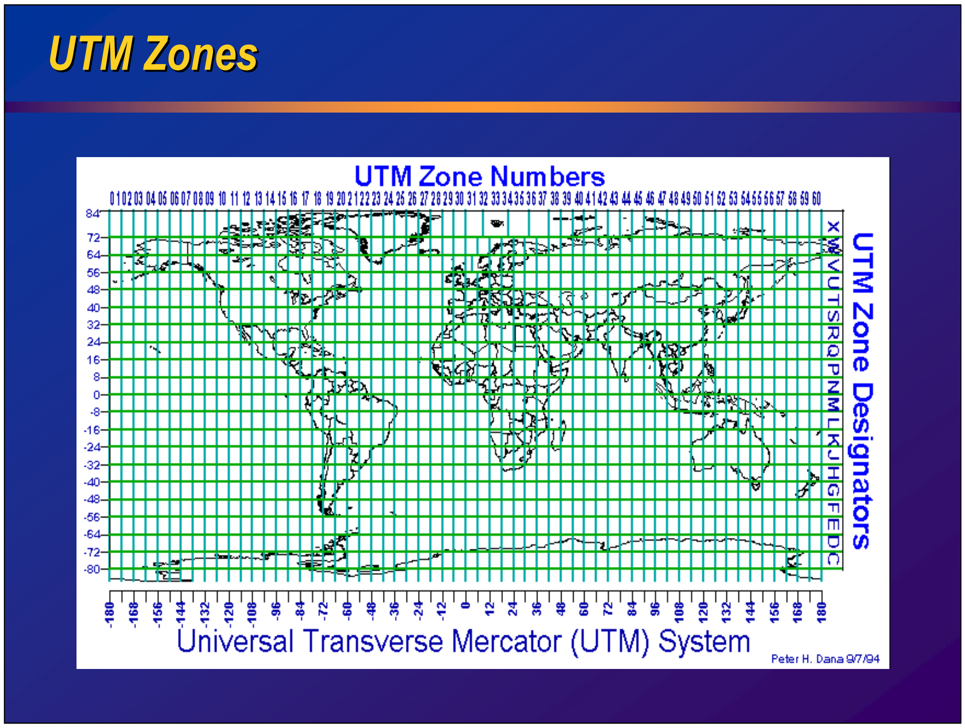
Note that a Geographic CRS is required in order to do this – i.e. it is an integral and essential part of the Projected CRS.



Here is an example from Angola.

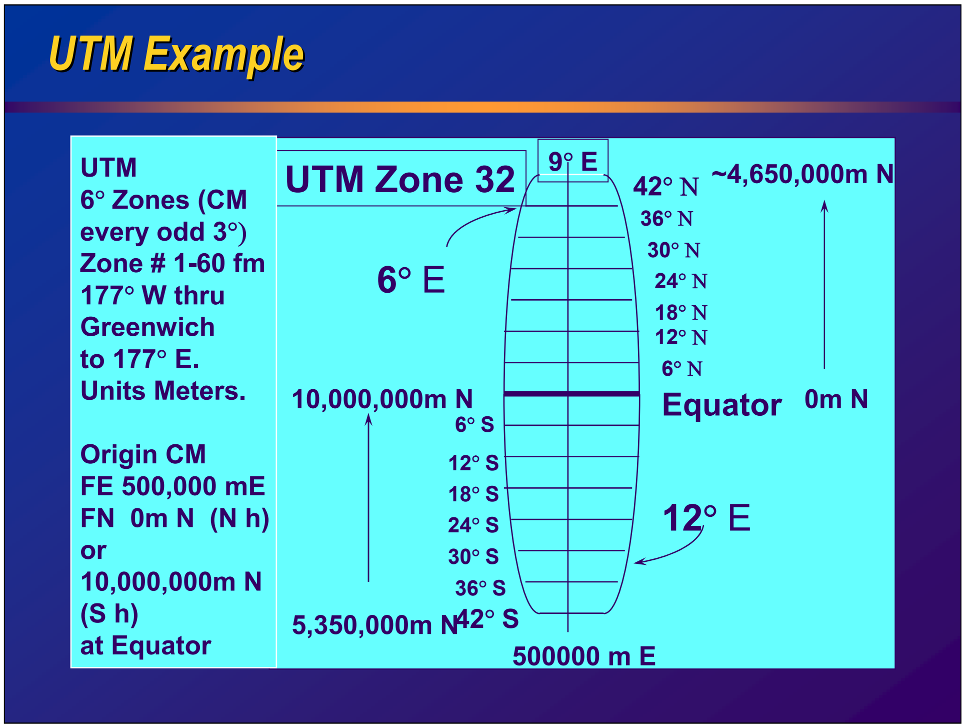
Note that exactly the same parameters fields are required.

In this case the Angola TM is very similar to UTM (see next few slides). It differs because it does not have a standard central meridian.



Here is a ‘catalogue’ diagram of the UTM projection. UTM is a special case of TM, with specifically defined parameters for any region of the world.

Zone number along the top, Latitude along the left side, longitude along the bottom and Zone designators for different ranges of latitude on the right (In my experience the latter are rarely used – and most people define UTM N or S for north or south hemisphere)

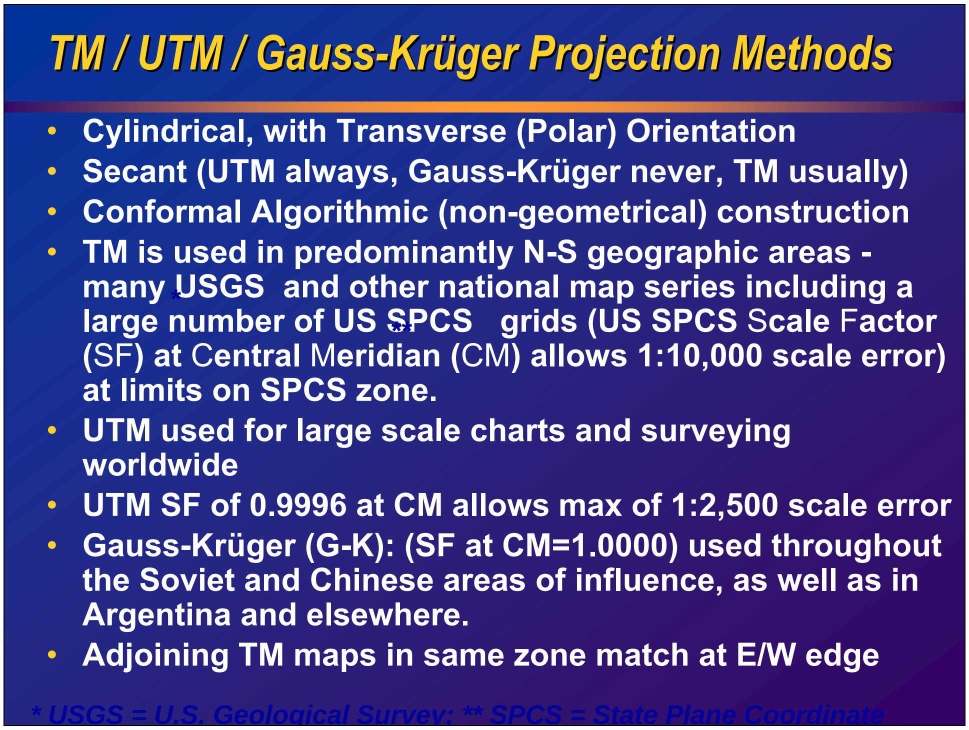


This is a ‘zoom in’ on part of a UTM zone – in this case UTM Zone 32 (shows both North and South).

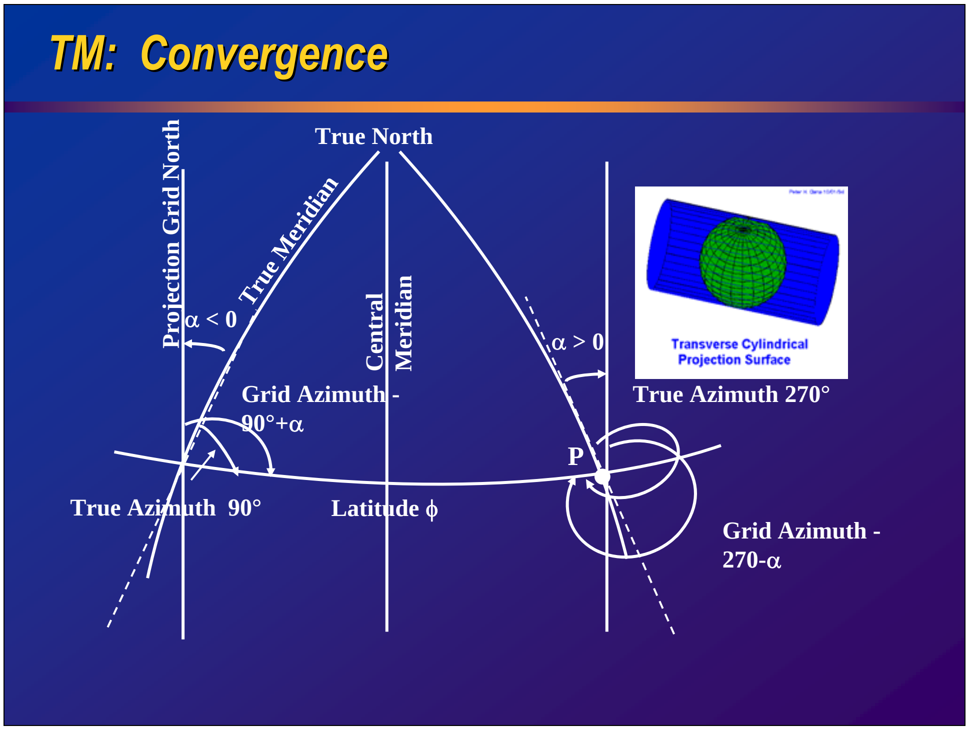
This figure shows only from 40 degrees South to 40 degrees North, but please be advised that each UTM Zone can be used as far toward the poles as 80 degrees Latitude (North or South).

The purpose of the slide is to show how the UTM convention is implemented in practice, and the effect on the easting and northing values within the zone.

Note that the central meridian is always and odd multiple of 3. Also the false northing is different in the northern and southern hemisphere. The 10,000,000m value in the southern hemisphere is to avoid having negative numbers for the Northing Coordinates



Here is a general discussion of the classification and use of the TM and UTM projection



Transverse Mercator projection is derived using the cylindrical method rotated so that the point of tangency or secancy is around a meridian through the poles instead of the equator (see inset)

Transverse Mercator Convergence.

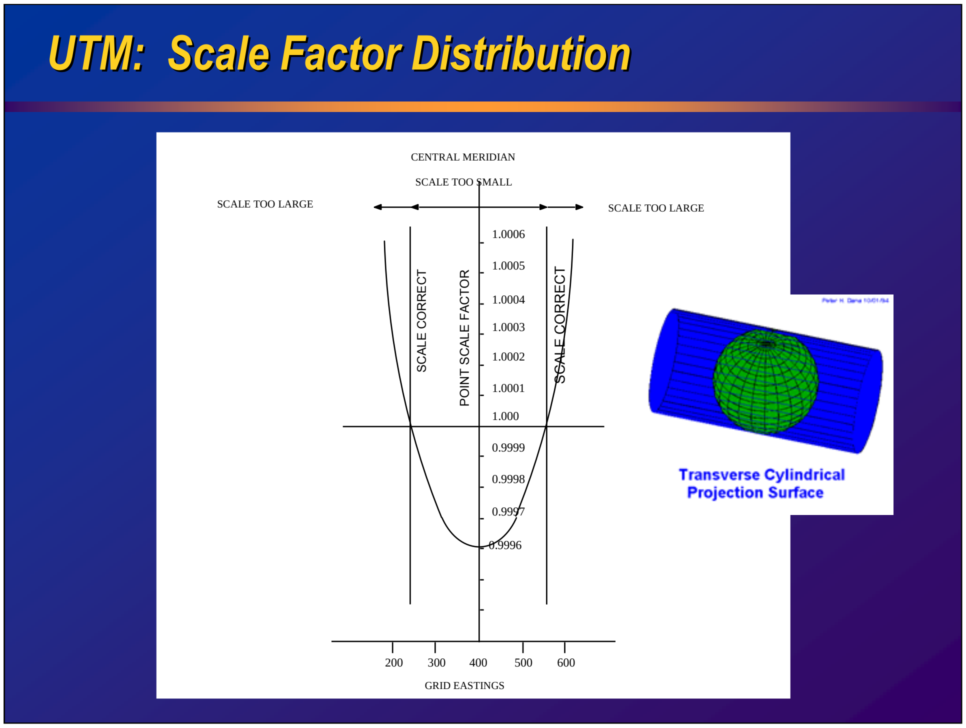
Convergence is the difference between the azimuth of the grid north on the projection (i.e. line of equal easting) and the meridian as plotted on the projection.

So an azimuth on the projection will not be the same as an azimuth on the earth's surface.

To understand how to apply the difference, I always draw a diagram. The meridian will always be concave towards the central meridian in such a way as it 'converges' on the pole for the hemisphere in which the map is located.

That is, Grid Azimuth = True Azimuth + Convergence α (α positive West of CM, and α negative East of CM in Northern hemisphere – signs are opposite in Southern hemisphere)

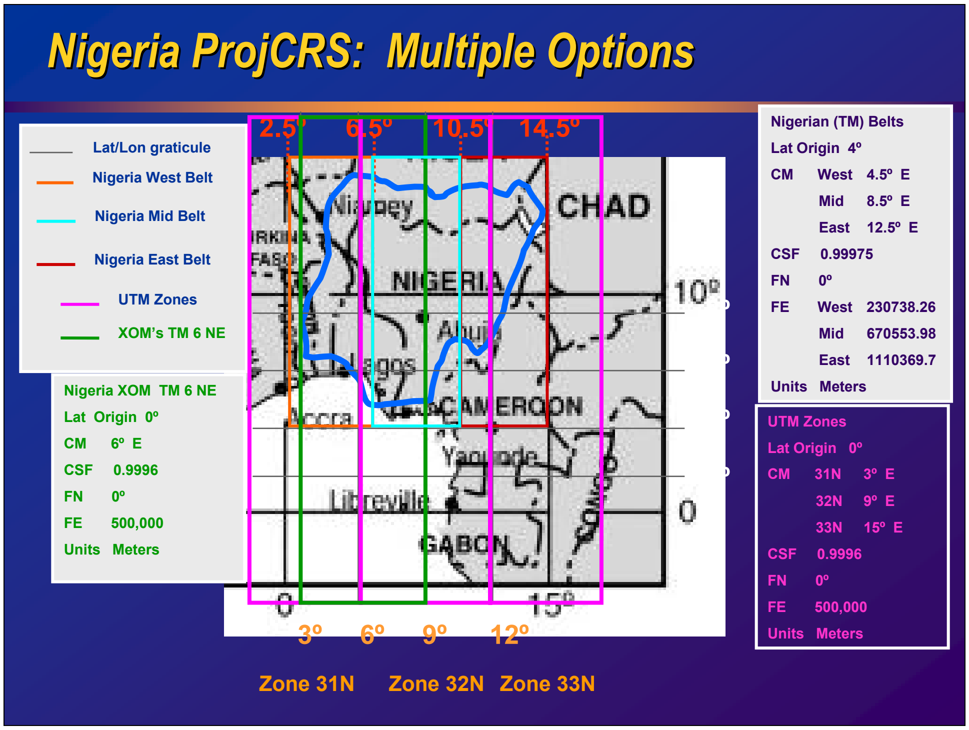
This is important when planning operations on a map – an offset well for instance.



Transverse Mercator Scale Factor:

Scale factor at the Central Meridian (Central Scale Factor) is usually a number close to unity such as .9999 or .9996 (as in this diagram). This means that a 10 km line on the earth's surface will be represented by 9.999 (1 part in 10000) or 9.996 kms (4 parts in 10000) respectively on the map. As a point moves away from the CM, the scale factor changes (increases). At a certain line, the scale factor will be unity (i.e. no scale distortion) then it will increase again out the edge of the projection design.

Starting the scale at a fraction allows the scale error to be distributed across a larger area without exceeding a certain amount anywhere in the map. Having said that, there are projections that use unity as the central scale factor (some of the Russian Topo maps do this)



Here is how the Nigeria projected CRS fit together.

There are 3 TM zones designed specifically for Nigeria onshore (and some offshore) work – West, Mid and East Belts (shown in red, green and brown) with the parameters in the upper right.

The three UTM zones are shown in yellow, parameters on the lower right.

The pale green shows a special TM designed to cover the whole Nigeria offshore. It has a CM of 6 degrees East, but otherwise has all the same parameters as the UTM.

The EPSG has chosen the convention of TM CM Hh for these “modified UTM” projections, where CM = Central Meridian, H = N or S hemisphere and h = E or W hemisphere. Hence the Nigerian 6 degree TM projection is called TM 6 NE. You will also see examples of TM 12 NE and TM 11.30 NE offshore Angola in this workshop

UTM Options: Northern South America

Datum	Ellipsoid	Projections (zones)
Aratu	International 1924	UTM 22-24 S
Corrego Alegre	International 1924	UTM 21-25 S
PSAD56	International 1924	UTM 17-22 N, 17-22 S
SAD69	GRS 1967 or International 1967	UTM 18-22 N, 17-25 S
SIRGAS 2000	GRS80	UTM 18-22 N, 17-25 S
WGS84	WGS84	UTM 18-22 N, 17-25 S

Total of over 60 ProjCRS – UTM only!

Here is a summary of all the datums and projections in Brazil.

Note there are 6 different datums, 3 of which use the same ellipsoid. Remember that in each case, that ellipsoid is attached to the earth in a different place, and thus the latitudes and longitudes from each cannot be matched.

Note also that SAD69 uses GRS 1967 sometimes called International 1967 ellipsoid. It is easy for the uninitiated to think that International is always the same. This is not so.

Note finally that every single one of these datums uses the same projection – UTM. This means that for a given area, a set of eastings and northings may be in any one of at least three different datums. Further it will not be possible to tell just by looking at the values!

Mixing Projections: Brazil Example

Datum	Latitude	Longitude	Local to WGS84	Local to Local
Aratu	20º 36' 13.2757"N	38º 56' 56.3341"W	236.7 m	220.56 m
SAD69	20º 36' 17.4283"N	38º 56' 50.1240"W	65.12 m	
WGS84	20º 36' 19.2794"N	38º 56' 51.2166"W		

Datum	Easting UTM 24S	Northing UTM 24S	Local to WGS84	Local to Local
Aratu	505,316.4 meters	2,278,317.4 meters	214.7 m	208.8m
SAD69	505,495.9 meters	2,278,424.1 meters	58.4 m	
WGS84	505,464.2 meters	2,278,473.1 meters		

Coordinates are of the SAME physical point

Here is an example of the consequences of confusing UTM coordinates in Brazil.

For a single location offshore Brazil all be expressed by any of the following sets of coordinates:

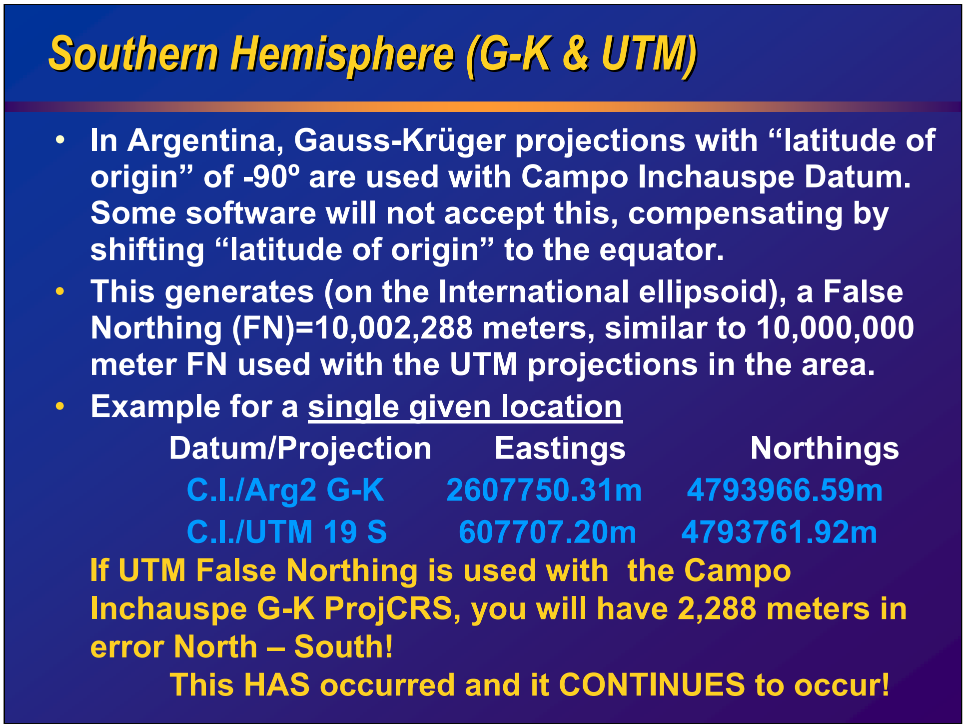
Datum/Projection	Easting	Northing
Aratu/UTM 24 S	505316.36m	7721682.65m
SAD69/UTM 24 S	505495.87m	7721575.90m
WGS84 /UTM 24 S	505464.21m	7721526.88m

The danger of using a wrong Datum (or GeogCRS) is evident from comparing the values, but which Datum you are using is not clear from any one set!

Using a different Projection draws attention to differences

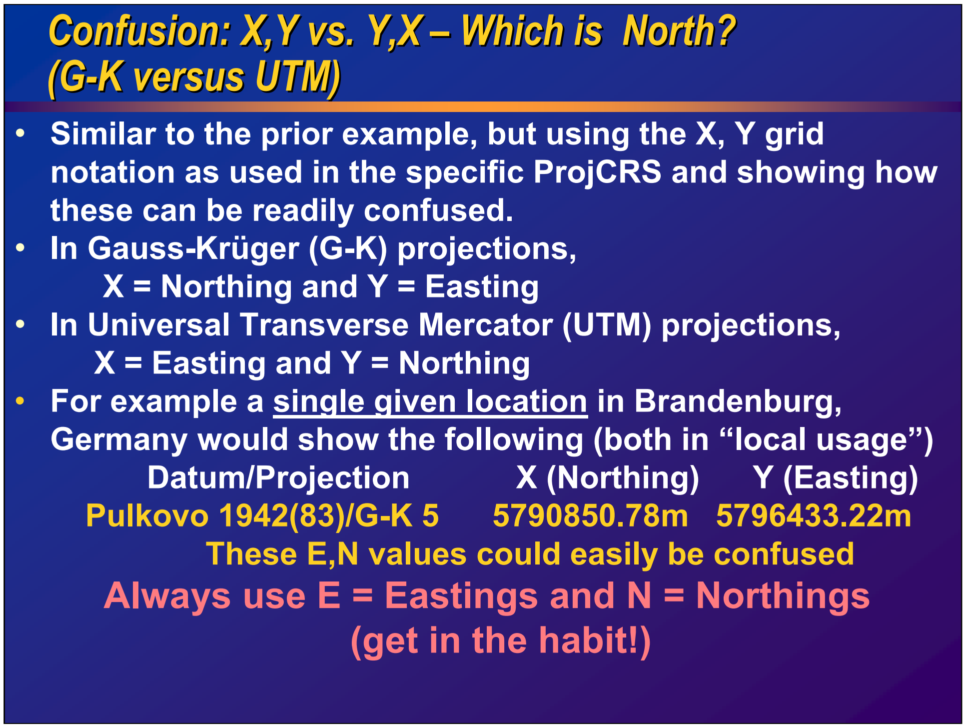
SAD69/AmPolyConic 6566892.88m 7648178.63m

Remember: All four sets of these coordinates are for the SAME physical point!



This slide is self explanatory!

Assume [Ass/U/Me] the wrong Projection on the Campo Inchauspe datum and you will have a 2288 meter positional error.



In Brandenburg, Germany (which was until 1990 a state in East Germany), this is very important because the northing and easting values look so similar you can easily get them confused. In their local system X = NORTHING and Y = EASTING! The example shown on the slide is for Pulkovo 1942(83) / Gauss Kruger zone 3 for a point with Pulkovo 1942(83) latitude and longitude of 52º 10' N and 13º 20' E. This Easting and Northing could easily be confused causing an error of six kilometers in both North and East directions should that happen!

In many other Projected CRSs, such a transposition is more easily spotted should it occur. For example the Argentine example from the previous slide (again for a <u>single given location</u> would show the following (both in "local usage")

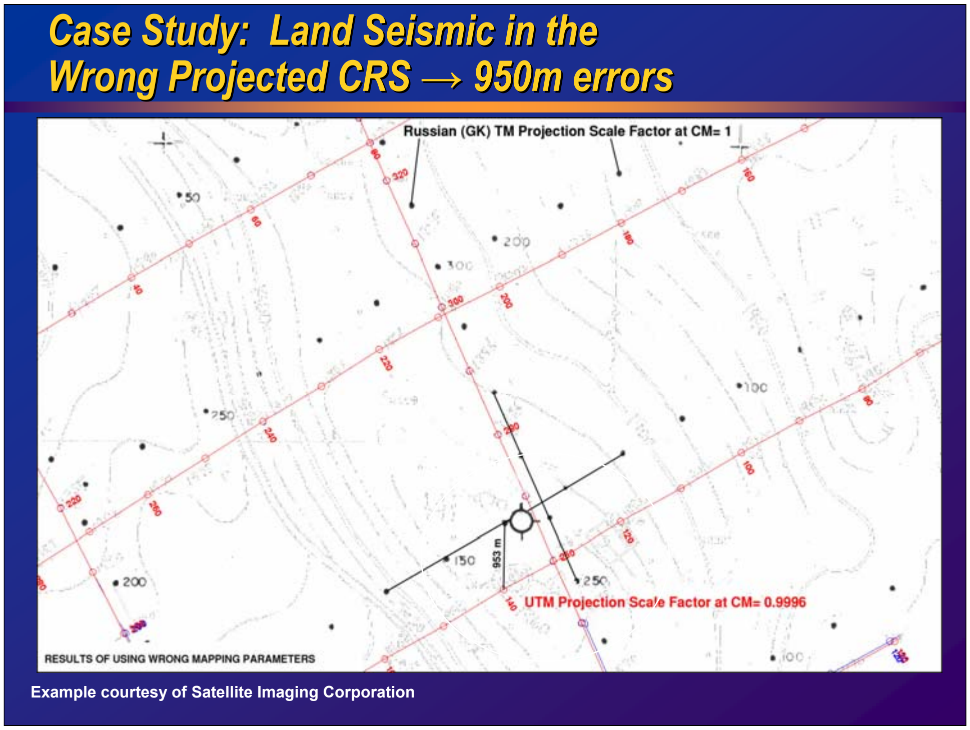
Datum/Projection	x	y
C.I./Arg2 G-K	4793966.59m	2607750.31m
C.I./UTM 19 S	607707.20m	4793761.92

There are even a few systems that use X,Y or E, N for "Southings" and/or "Westings" – both in Northern and Southern hemispheres. In the Northern Hemisphere these are pretty much restricted to some older Danish Projected CRS used in Iceland, the Faroe Islands and Greenland. For example:

- Scoresbysund 1952 / Greenland zone 5 east and Scoresbysund 1952 / Greenland zone 6 east (where N = north, E = West)
- Lisbon 1890 (Lisbon) / Portugal Bonne, an older Portuguese ProjCRS (where the CRS axis are P = south, M = West)

In the southern hemisphere, the "south-orientated" projections and ProjCRSs are used in South Africa and Namibia. For example:

- South African Coordinate System zone 31 on the Cape Datum (where Y = Westing and X = Southing), and
- South West African Coord. System zone 13 on the Schwarzeck Datum (again with Y = Westing and X = Southing, but with the non-standard linear measure of German Legal Meters in this case).

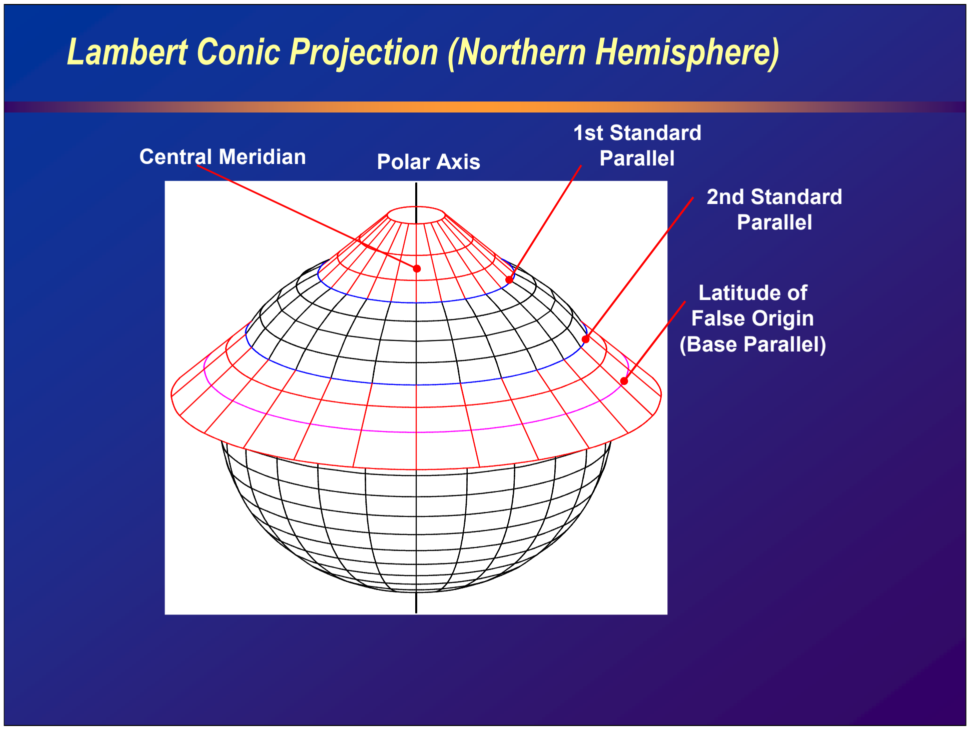


The difference of using two different projections –

Russian Gauss-Krüger Projection vs. UTM Projection can cause errors of almost a kilometer – even if on the same datum (which is NOT shown on this example):

Conical Projections

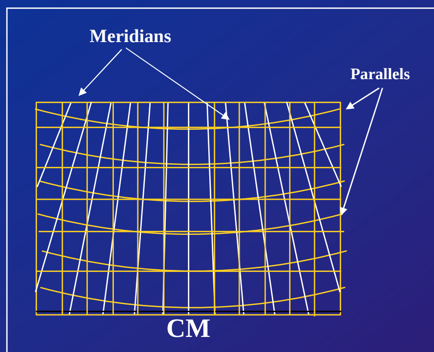
- **Lambert Conic Conformal**
  - 1 standard parallel or 2 standard parallels
  - 2 standard parallels (Belgium variant) (older maps only)
  - (old maps only)
  - Krovak Oblique Conformal Conic (Czech Republic)
- **Lambert Conic "Near Conformal"**
  - Army Map Service, 1 standard parallel
  - (not supported in ESRI ArcGIS 9.2)
- Lambert Conic Conformal projections **minimize North-South distortions**
- Used extensively in US State Plane Coordinate system (SPCS) for E-W oriented areas (e.g., KY, TN.) Also used in Texas with 5 zones to cover the required latitudes)

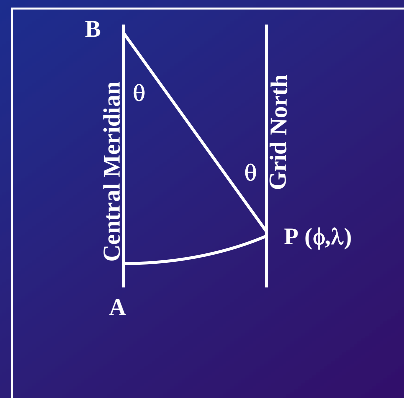


Fitting a cone to a reference ellipsoid (representing the earth's geoid) yields a Lambert Conic Conformal Projection. If the cone is tangential to the ellipsoid surface this becomes a Lambert (Single Standard Parallel) projection. More commonly, the cone will cut into the ellipsoid, yielding a Lambert Two Standard Parallel Projection.

The Two Standard Parallel projection reduced to the Single Standard Parallel projection at tangency of the cone to the ellipsoid.

Lambert Conic Convergence



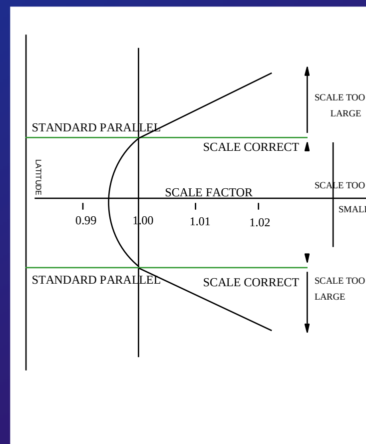


Parallels of latitude project as circular arcs concave to the nearest pole. Meridians of longitude are straight lines converging towards the nearest pole. Meridians and Parallels are orthogonal.

The Lambert projection uses a cone as the projection surface. Convergence is applied by inspection with the meridian convex towards the Central Meridian, and the nearest pole.

Lambert Conic Scale Distortion

- Scale is constant in the E-W direction but varies in the N-S direction
- Scale is correct along the standard parallels. Too large outside them and too small inside them
- Variation in scale in N-S direction is shown opposite
- The projection is limited in N-S extent by the amount of distortion allow



Scale factor distribution is similar in appearance to Transverse Mercator but varies north south as opposed to east west.

Lambert Conformal Conic Projections

- Conic, Polar orientation
- Secant (2 Standard Parallels) or Tangent (1 S.P.)
- Conformal (Shape distortion is very small)
- Algorithmic
- Great Circles are (approximately) straight lines
- Parallels are arcs of concentric circles expanding in distance at edges, contracted between standard parallels
- Meridians are straight lines
- Used for mapping areas of large E/W extent including some US States (SPCS) and world series aeronautical charts, hurricane tracking charts

Here is a general discussion of the classification and use of the Lambert projection

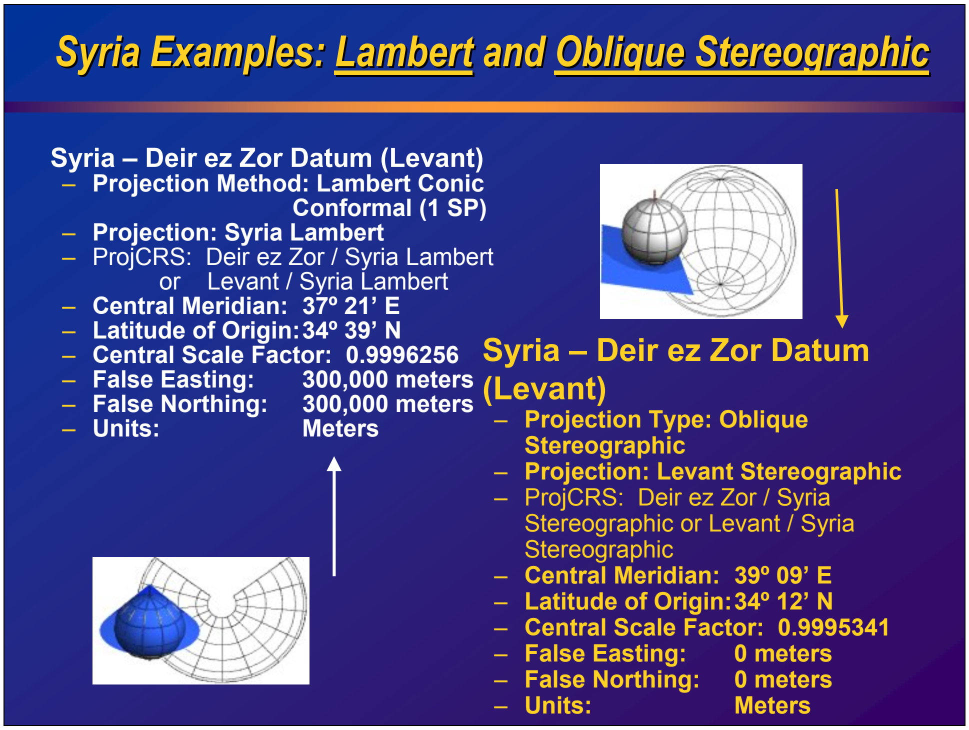
Example: Lambert ProjCRS, USA

- Geodetic Datum: North American Datum of 1927
- Coordinate System: Lat (degrees, Long (degrees)
- Projection Type: Lambert Conformal Conic (2 SP)
- Projection Name: Louisiana South Zone
- ProjCRS Name: NAD 27 / Louisiana South Zone
- Central Meridian: 91º 20’ W
- Latitude of Origin: 28º 40’ N
- Latitude 1st Standard: 29º 18’ N
- Latitude 2nd Standard: 30º 42’ N
- False Easting: 2 000 000.00
- False Northing: 0.00
- Units: US Survey Feet (ftUS)

Here is a fully qualified Lambert Projection CRS. Note again the inclusion of the Geographic CRS (Datum) in the ProjCRS name (good metadata habit to use!)

Other Projections of Interest

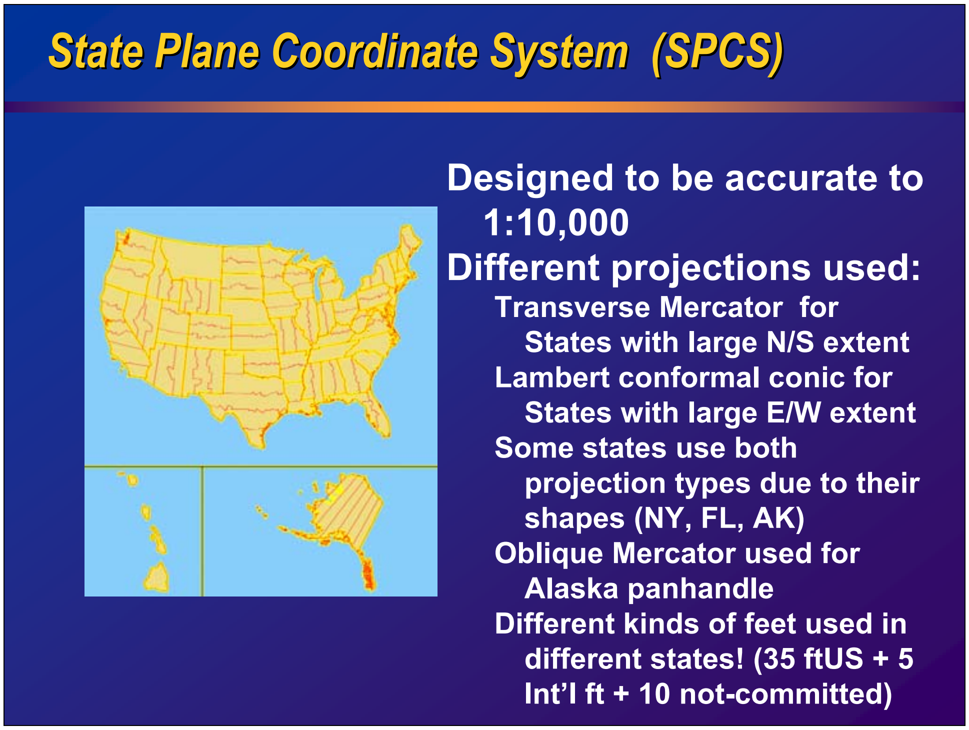
- Albers Equal Area Projection
  - Used when equal area proportionality is important.
- Lambert Azimuthal Equal Area Projection
  - An alternate equal area projection
- Stereographic Projections
  - Projection on to a tangential plane from the point on the opposing diameter of the ellipsoid
  - Used for polar areas
  - Oblique Stereographic to map specific shaped areas
- American Polyconic Projection (brought back into usage for offshore Brazil by the Brazilian government)
  - Neither conformal nor equal area
  - Distortion free only along the longitude of origin



Syria Projections

1. Lambert
2. Oblique Stereographic

The latter is formed using the planar projection surface but oriented at an oblique angle with respect to the earth's surface – i.e. not at the pole or the equator. The point of projection for stereographic is the point on the earth's surface opposite the point of tangency of the planar surface. This is the fully qualified Oblique stereographic projected CRS in use in NE Syria. Again note that the Geographic CRS is an integral part of this



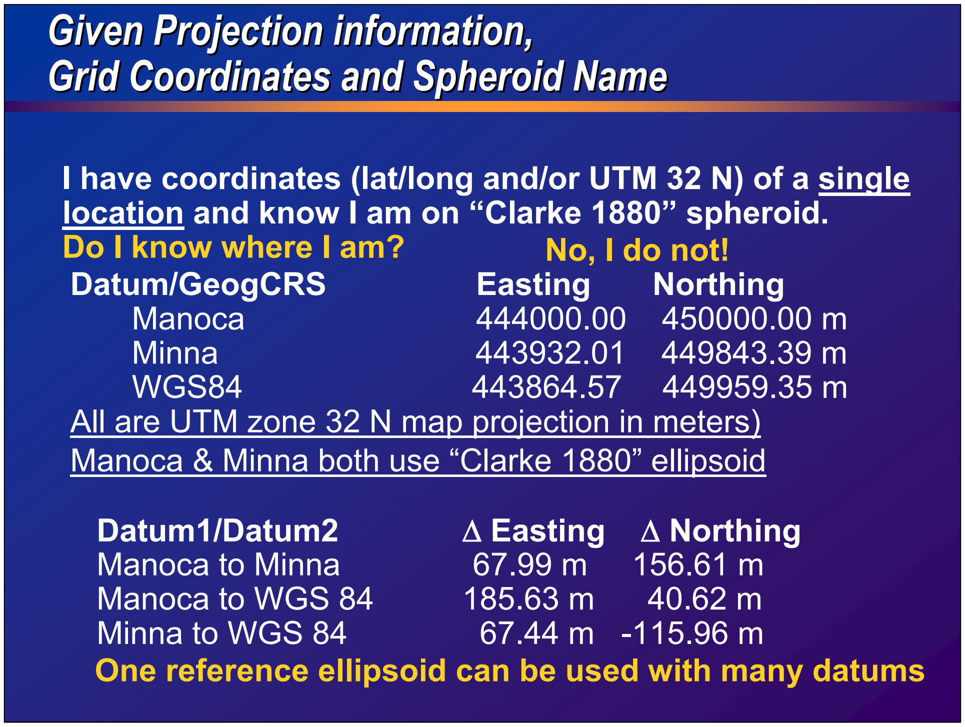
The United States State Plane Coordinate System used both Lambert and TM projections.

The States with long north south extent, generally use TM, and the States with long east west extent generally use Lambert.

Some states use both, and Alaska uses oblique Mercator for the pan-handle.

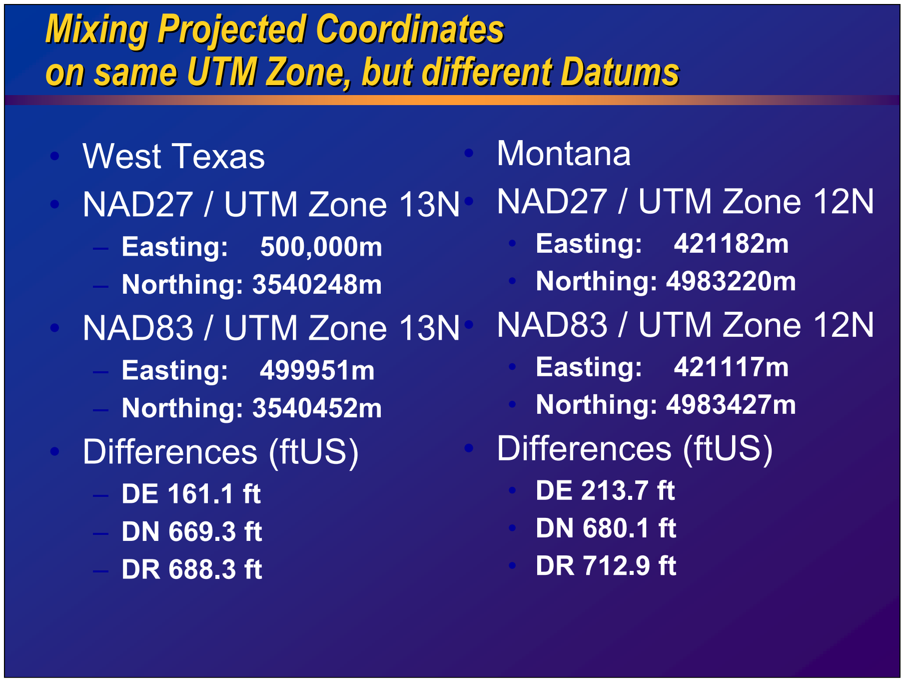
State Plane is set up to give less than 1:10000 error in scale, which is why there are so many zones.

The zones for NAD27 and for NAD83 differ, both in extent, parameters and units. Be careful not to confuse them.



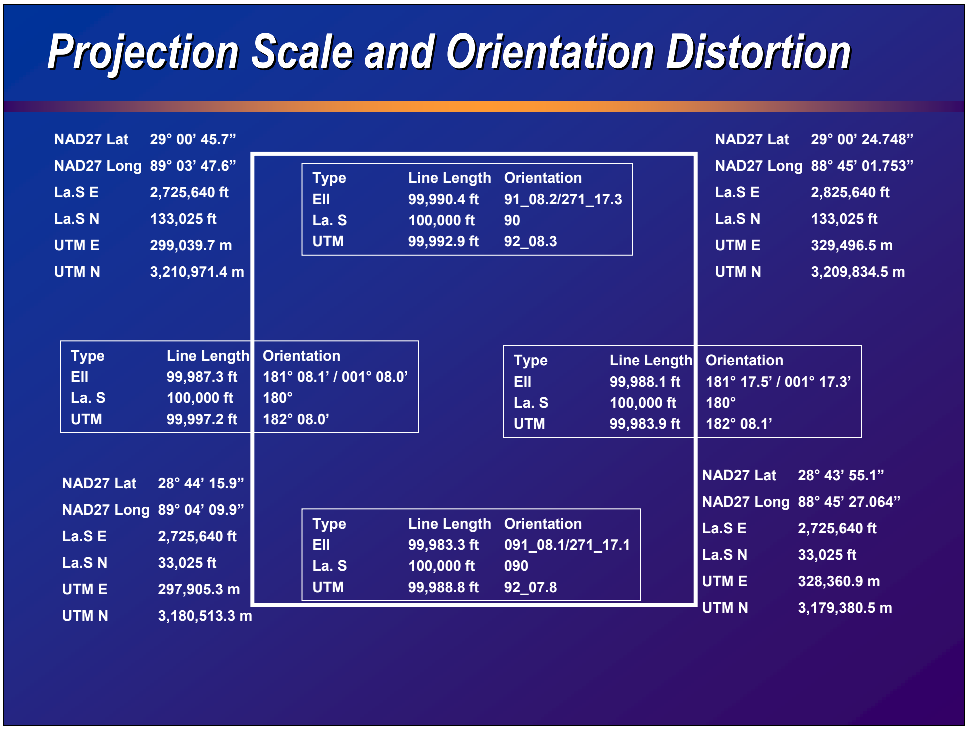
•Note the differences you get if you confuse the Projected CRS with respect to their respective Geographic CRS (Datums)

•Just a reminder, both these datums use Clarke 1880, but the Geographic CRS (Datums) are different, because the ellipsoids are attached to the earth at a different point.



Here is a comparison of UTM coordinates in Texas and Montana, if the Geographic CRS is confused between NAD27 and NAD83, where both are projecting into UTM.

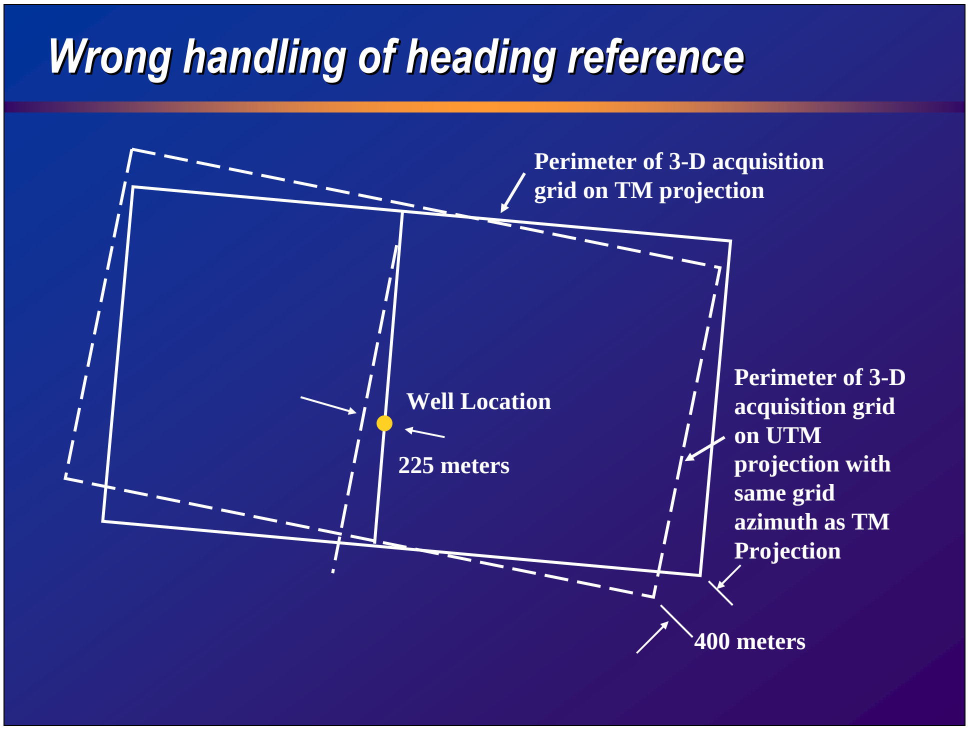
Thus the differences represent the result if the UTM Projected CRS is assumed to be on the wrong datum.



This slide shows a 'box' area, where each corner has coordinates in Latitude and Longitude on the NAD27 Geographic CRS, Easting and Northing Coordinates in Louisiana South, and in UTM Meters.

I have shown the respective length and orientation of each side of the box, based on each set of coordinates.

Note that although the corner coordinates represent the exact same point on the surface of the earth, the Projected CRS distortion (scale and convergence) create an apparent change in length and orientation. This is because the different projected CRS distort differently.



Related to the previous slide, it is important to convert each corner, and not one corner and assume the same orientation.

This example shows what happens if this rule is ignored. Note that the last slide indicates that the grid orientation of a given line on the surface of the earth is not the same from one projection to another.

More Confusion in Geodesy

Reference Orientations: (3 “major” Norths)

- True North = Direction of the meridian at a point
- Grid North = Differs from True North by convergence
- Magnetic North = Differs from True North by Declination

Reference Units: (13 different feet and 2 meters)

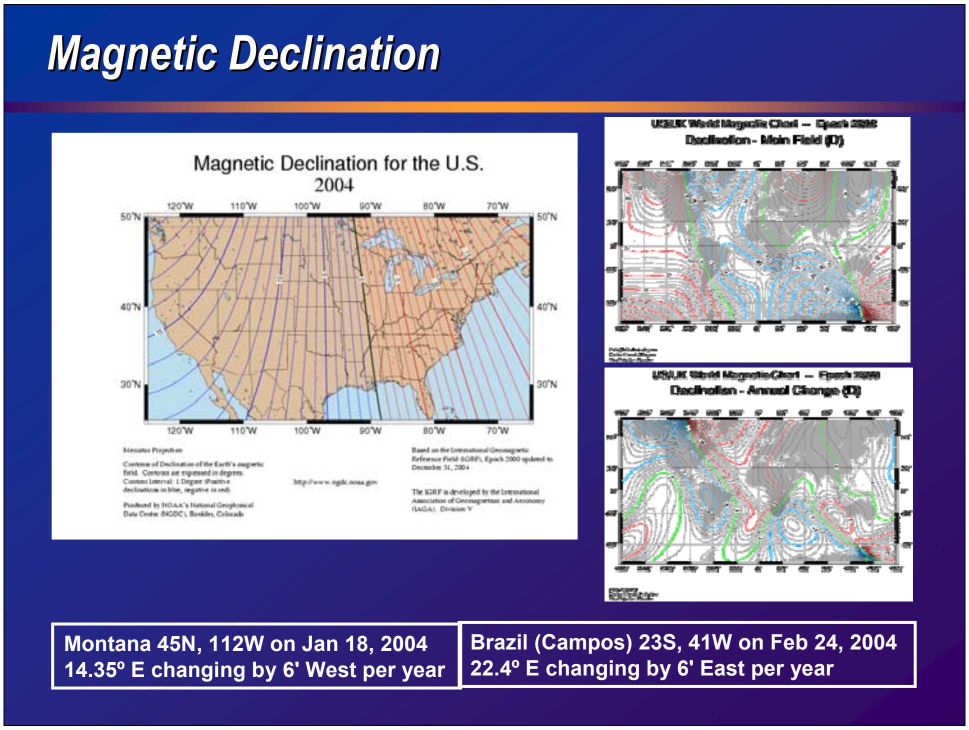
- Biggest Problem = U.S. Survey Ft vs. International Ft
- Other Feet = Clarke’s Foot, Sears 1922, 2 for Benoit (both 1895), Gold Coast Ft., 4 Indian Ft. (1865, 1937, 1962 & 1975) and 2 British Feet (1865 & 1935),
- Currently 2 meters = Intl Meter and German Legal Meter
- Other linear units include Chains, Links, and Yards (in almost as many variations as the foot to meter relationships)

Here is a summary orientation references.

It is important to apply corrections to real world observations before plotting or computing based on projection CRS.

It is equally important to annotate any plans based on the projected CRS that are to be applied in real world.

These rules are especially important when managing offset well plans and data.



These diagrams show the magnetic declination in USA and the world. The third diagram shows the world rate of change of magnetic declination on an annual basis.

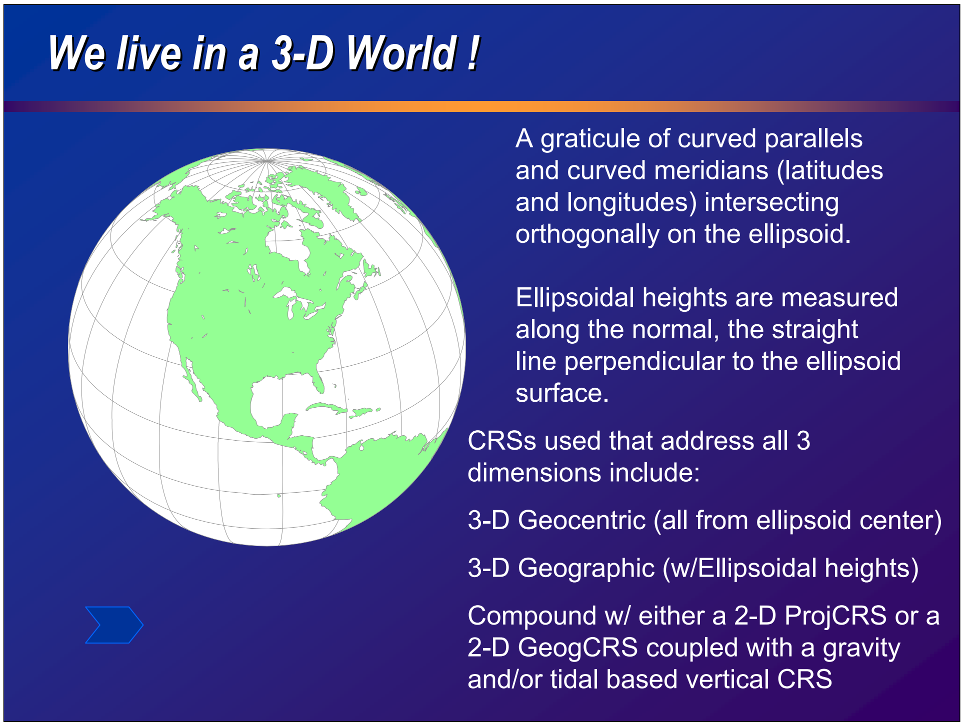
These diagrams and some handy online computations can be found on the web at:

http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/fldsnth1.pl

Downhole Surveys: Varying "North" Orientation References

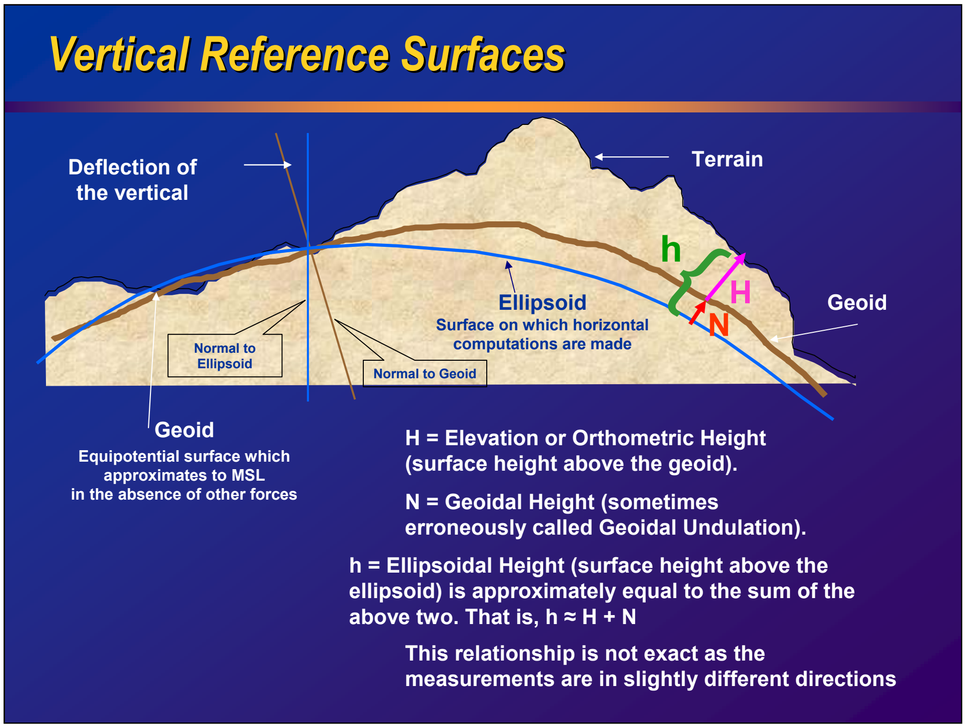
- From various well documents and databases
  - Casing MWD: Magnetic (referenced to Magnetic North)
  - Below Casing: Inertial (referenced to True North)
  - Rig orientation: (referenced to Grid N or True N?)
- When data are merged:
  - Was the magnetic data adjusted to grid or true N?
  - Has the rig orientation used the same North reference?
  - Is all this documented for other departments / users?
- Do specifications lead to consistent results?
- Was there QC of the onsite methods and data?
- Is there a clear and informative report?

Quality Control and audit of down-hole surveys is notoriously lax. These data, so critical to geologic interpretation should always be checked and always treated with suspicion!



Note that the term 3-D in geodesy has nothing to do with 3-D seismic – other than the coincidence that they both contain three dimensions.

3-D in geodesy means that we are working in a Coordinate Reference System that has both horizontal and vertical coordinates.



You have seen a similar slide earlier, showing the fundamental issues of establishing a local Geodetic Datum. The slide is shown again here but modified to illustrate the vertical reference surfaces and the relationships between them.

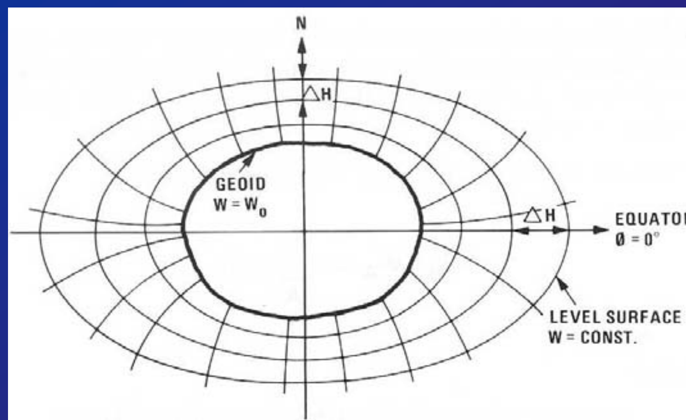
The elevation (or orthometric height) of a point on the earth's surface measures the distance (height) of the point to the geoid in the direction of localized gravitational " pull " on the instrument's plumb bob.

The ellipsoidal height is the height of the surface point above the reference ellipsoid, measured in the direction normal to the ellipsoid. If the point is below the reference ellipsoid this value will be negative.

The angular difference in the directions in which these two "heights" are measured is called "Deflection of the Vertical" which was discussed earlier under "establishment of a local datum". Different locations coupled with different ellipsoids and their datum origins produce different deflections. Some are very nearly zero (e.g., the flat areas at Meades Ranch, Kansas for NAD 27) whereas some are very large (e.g., in the Himalayas and Pacific trenches near Tokyo Observatory for Tokyo Datum).

Diagrammatic relationships are shown here between elevation (orthometric height), ellipsoidal height and geoid height (sometimes called geoidal undulation). Because of deflection of the vertical, these heights are not co-linear, though the effect of deflection on the height measurements is negligible.

Geopotential Surfaces, the Geoid, Plumb Lines



Elevations are measured w.r.t. the geoid, the (physical) surface whose equipotential value (W) is that of Mean Sea Level ($W=W_0$). Elevations with respect to the geoid are called "orthometric heights"

Vertical Datums

A Vertical Datum is a set of fundamental elevations to which other elevations are referred. This set may be a single elevation or derived from many individual reference elevations

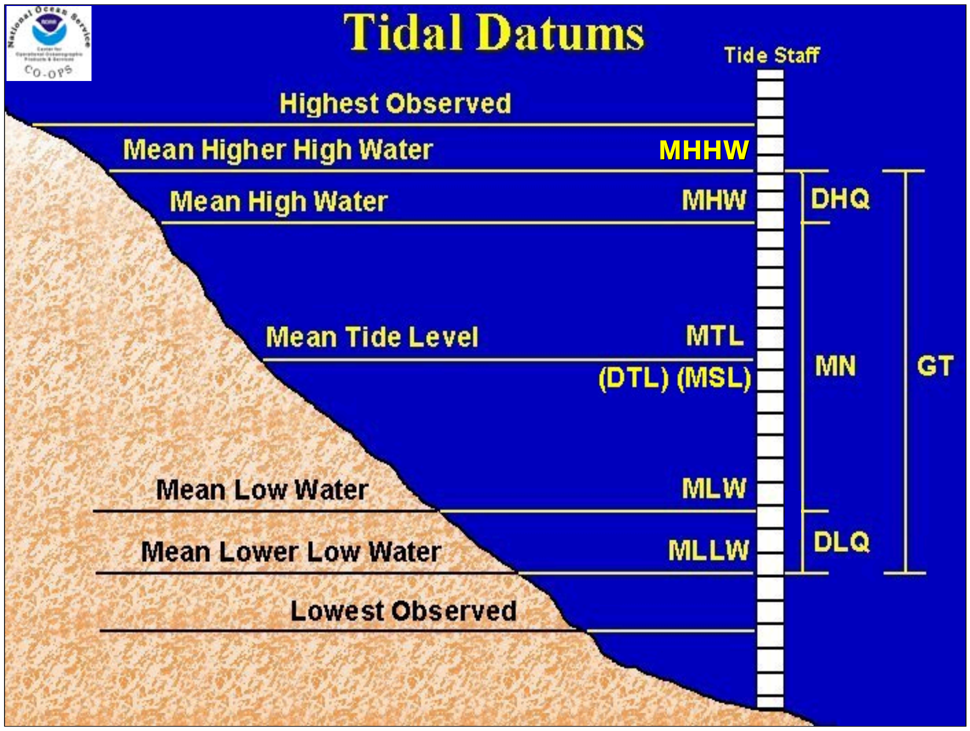
Vertical Datum Types

Local **– "Kelly-Bushing", "ground level", "sea level", and assorted other local references**

Geodetic **– Either directly or loosely based on Mean Sea Level at one or more points at some epoch (NGVD 29, NAVD 88, OSU91A, EGM96, etc.)**

Tidal **– Defined by direct observation of tidal variations over some period of time at a specific location (or locations). Examples: (MSL, LAT, MLLW, MLW, MHW, MHHW, etc.)**

Each of the above terms will be defined over the next several slides.



•Highest and Lowest Observed are not a tidal datum or a computation.

•The acronyms can be found in our reference Glossary

Standard Method (MTL, MSL, Mn, DHQ & DLG are known):

•MLW= MTL-(0.5*Mn)

•MHW= MLW+Mn

•MLLW= MLW-DLQ

•MHHW= MHW-DHQ

•DTL= 0.5*(MHHW+MLLW)

•GT= MHHW-MLLW

MRR Method (MTL, DTL, MSL, Mn & GT are known):

•MLW= MTL-(0.5*Mn)

•MHW= MLW+Mn

•MLLW= MLW-0.5*GT

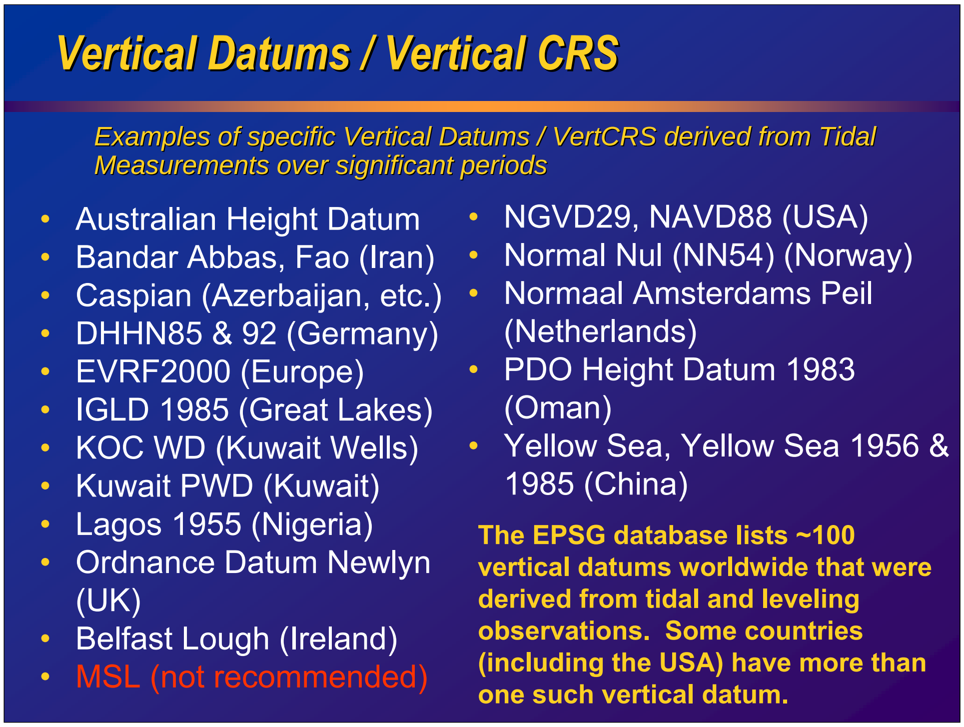
•MHHW= MHW+GT

•DHQ= MHHW-MHW

•DLQ= MLW-MLLW

•LAT = Lowest Astronomic Tide

GT is known as the spring or diurnal range depending on what coast it is on.



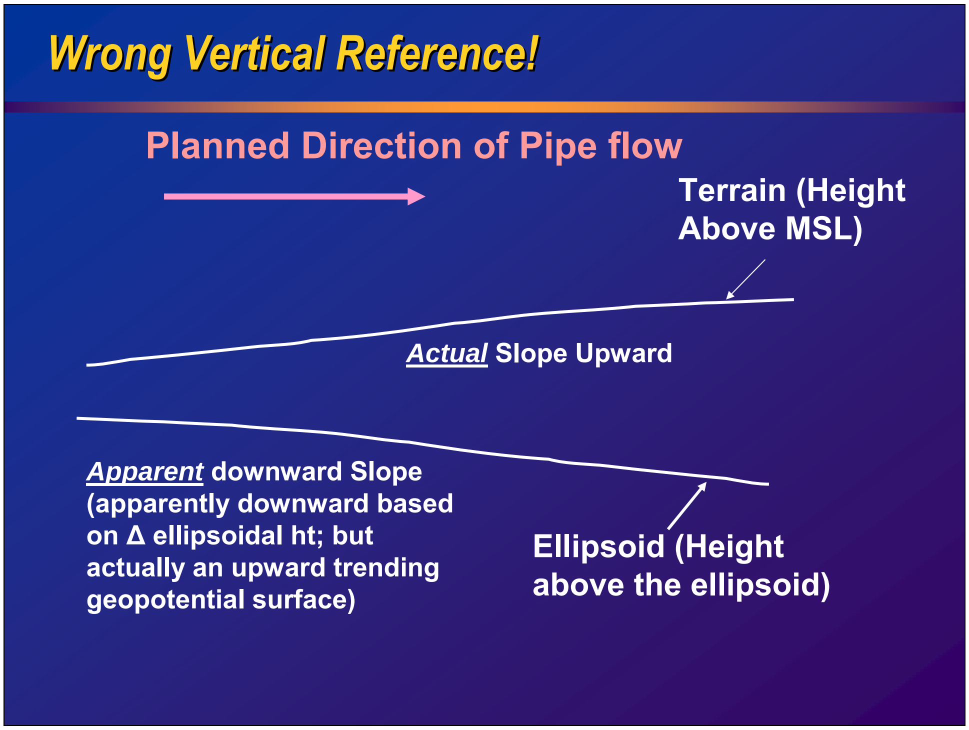
As an example, let us examine the International Great Lakes Datum, IGLD 1985 and its predecessor IGLD 1955:

Because of movement of the earths crust, the "datum" or elevation reference system used to define water levels previous within the Great Lakes-St. Lawrence River system must be adjusted every 25 to 35 years. The current datum was known as the International Great Lakes Datum, 1955 (IGLD 1955). These few questions briefly explains the development and impacts of the revision to this datum, known as the International Great Lakes Datum, 1985 (IGLD 1985). The date, 1985, is the central year of the period 1982- 1988 during which water information was collected for preparing the datum revision.

(Above from http://www.lre.usace.army.mil/greatlakes/hh/newsandinformation/iglddatum1985/whatisigld/)

MSL is the local mean sea level and should not be confused with the fixed datums of NGVD (sometimes referred to as Sea Level Datum of 1929) or NAVD 88. NGVD is a fixed datum adopted as a standard geodetic reference for heights. It was derived from a general adjustment of the first order leveling nets of the U.S. and Canada. Mean sea level was held fixed as observed at 26 stations in the U.S. and Canada. Numerous adjustments have been made since originally established in 1929.

NAVD 88 involved a simultaneous, least squares, minimum-constraint adjustment of Canadian-Mexican-United States leveling observations. Local mean sea level at Father Point/Rimouski, Canada was held fixed as the single constraint. These fixed datums do not take into account the changing stands of sea level and because they represent a "best" fit over a broad area, their relationship to local mean sea level is not consistent from one location to another.



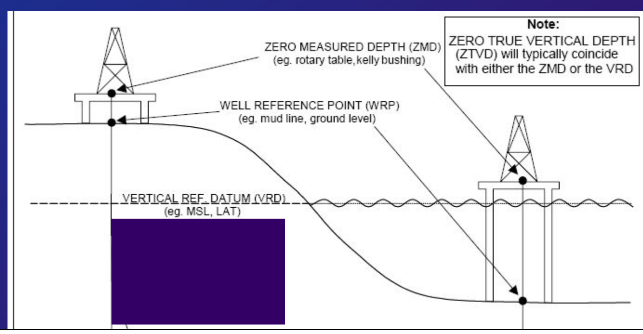
This problem shows what might happen when ellipsoidal heights are considered as Mean Sea Level elevations.

Imagine that the geoid and the ellipsoid are in fact diverging – i.e. one surface is increasing and one decreasing relative to one another. If you think the pipe route is trending downwards, when it is going upwards reference to gravity (geoidal surface) then the capacity of your pumping facilities will not meet the requirement.

This ACTUALLY happened!

Local Vertical Datums / CRS: the Danger of their Use

- The use of elevations or heights referenced to “Kelly Bushing”, “Rotary Table” , “Drill Floor” and/or other drilling equipment references is valid only so long as the same drilling rig is used.
  - Once these heights enter a database as “heights” with no other vertical reference surface, it is difficult if not impossible to relate them to a “proper” vertical CRS.



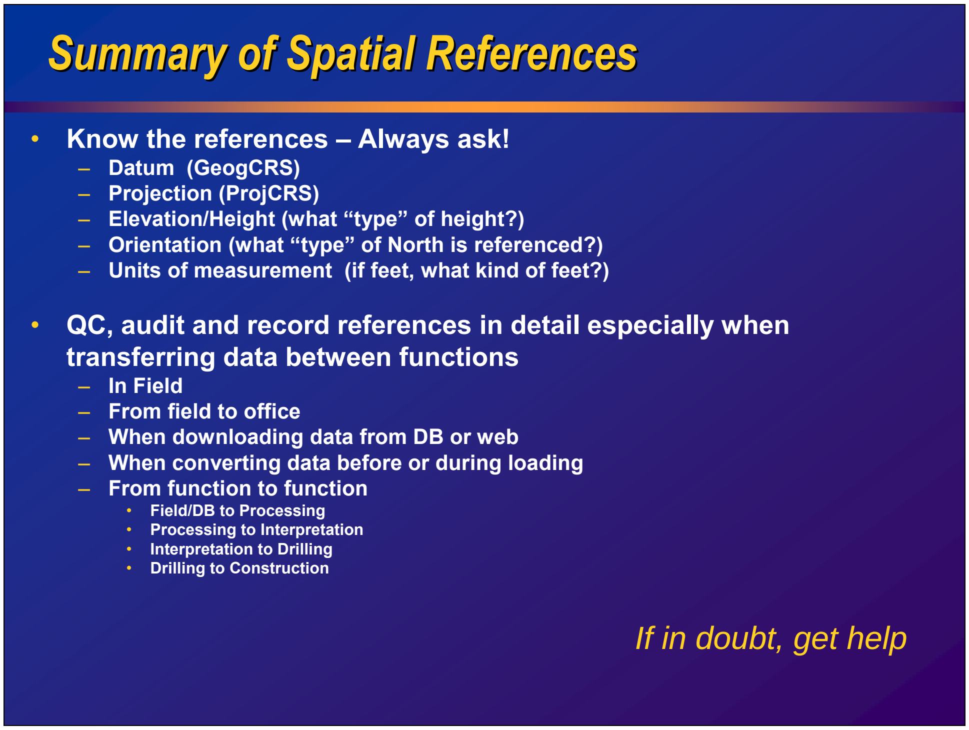
The following has been extracted from the UKOOA* Data Exchange Format P7/2000 Format for Well Deviation Data’s (section 3.1) on Depth References:

The ABOVE FIGURE ON THIS SLIDE, followed by the following text.

“Drillers reference along-hole depth (invariably referred to as measured depth, MD) to a level at or just above the level of the drill floor (RT=rotary table, KB= kelly bushing). In this document, this reference level is referred to as zero measured depth (ZMD). ZMD is rig-dependent, so may be different between a parent well and its sidetracks. In addition to ZMD, some Operators define a permanent reference point further down the well, called the well reference point (WRP). The WRP is typically at or close to ground level (land rigs) or sea bed (offshore rigs). The absolute elevation of a well in space is determined from the elevation of ZMD and/or the WRP with respect to the vertical reference datum (VRD). VRD is typically Mean Sea Level (MSL), but may be Lowest Astronomical Tide (LAT) or a land survey [vertical] datum.”

“For calculated data, the vertical depth reference is called zero true vertical depth (ZTVD). This may coincide with ZMD (the usual practice of drillers), with MSL (geoscientists) or may have a separate definition.”

*UKOOA = United Kingdom Offshore Operators Association



It is vital to always record the references you are using, and demand them of others who supply you with data. Do not be put off on this!

If you are managing or supervising projects, you should ensure that you or someone you appoint is overseeing and checking the work, and the final report.

Always remember that the next group (geologists, drillers, facilities folks) need to know what you did, and need to make sure that what you download, they upload correctly, especially if they are using different references.

Common Problems when handling Positioning Data

- Latitude/Longitude provided without reference to a Datum or Geographic Coordinate Reference System
- Easting/Northing provided without reference to Projected Coordinate Reference System (each of which is also integrally tied to a specific Geodetic Datum)
- Assumption often made that two interpretation projects are on the same local datum, when that may not be the case
- Incorrect parameters selected when converting geographic coordinates (Lat/Longs) to projected coordinates (Easting/Northing) values

Common Problems when handling positioning data

- Assuming an incorrect UTM Zone
- Not using the correct units (e.g., wrong type of foot unit for US domestic data)
- Digitizing positions from maps with incomplete or nonexistent geodetic parameters . . . and then improperly assigning them a “fake” (unknown or assumed) geodesy
- Also concerning digitized data, not respecting original source map scale.
- Assuming: “It is in the database so it must be accurate…..”

To ensure you do not have these problems

Make sure when working with positioning data that you have complete geodetic information.

For Latitude/Longitude data:

- **Name of the Datum and Geographic CRS**

For Easting/Northing data:

- **Complete name of the Projected CRS**

  OR

- **Datum Name and Complete Projection Name (including zone # and/or other specific identifier.)**

It is usually best to also ask for the specific parameters on above to ensure that the parameters match names given

QC Actions

- **When you receive 3-Parameter Datum Shifts**
  Make sure that the shifts are defined from the desired Datum1 / GeogCRS1 to Datum2 / GeogCRS2

- **When you receive 7-Parameter Datum Shifts**
  Make sure that you understand what rotation convention your application uses

  Have the provider give you a test point so that you can verify that you are achieving the same results

Example Parameter list for ProjCRS

ProjCRS Name: NAD83(HARN) / Texas Central (ftUS)

which implicitly tells us:

Datum Name:	NAD83(HARN)
Ellipsoid Name:	GRS80
Semi-major axis:	6378137
Inverse Flattening:	298.25722210
Prime Meridian:	Greenwich
Units:	Meter
Projection:	SPCS83 Texas Central zone (US Survey feet)
Latitude of False Origin:	29 deg 40 min N
Longitude of False Origin:	100 deg 20 min W
Lat. of 1st Std Parallel:	31 deg 53 min N
Lat. of 2nd Std Parallel:	30 deg 07 min N
Easting at False Origin:	2296583.33 ftUS
Northing at False Origin:	9842500 ftUS

Remember!

Latitudes and Longitudes
are not unique
unless qualified with Horizontal Datum name!

Heights are not unique
unless qualified with
Vertical Datum and units

Orientations are not unique
unless qualified
with “type” of North reference

Most important lesson to remember

EPSG database (www.epsg.org) comprises:

- Datums & Coordinate Reference Systems
  - Geographic 2D, Geographic 3D, Geocentric and Projected CRS
  - Vertical, Engineering [local] and Compound CRS
- Geodetic Transformation Data
  - Concatenated Ops [sequential steps are required]
  - Single geodetic transformations of all types
  - Transformations between vertical systems
- Ancillary Data
  - Ellipsoids, Prime Meridians, Units of Measure, etc.
- Associated reports and forms to access data
- Database available in SQL and MS Access 97

References

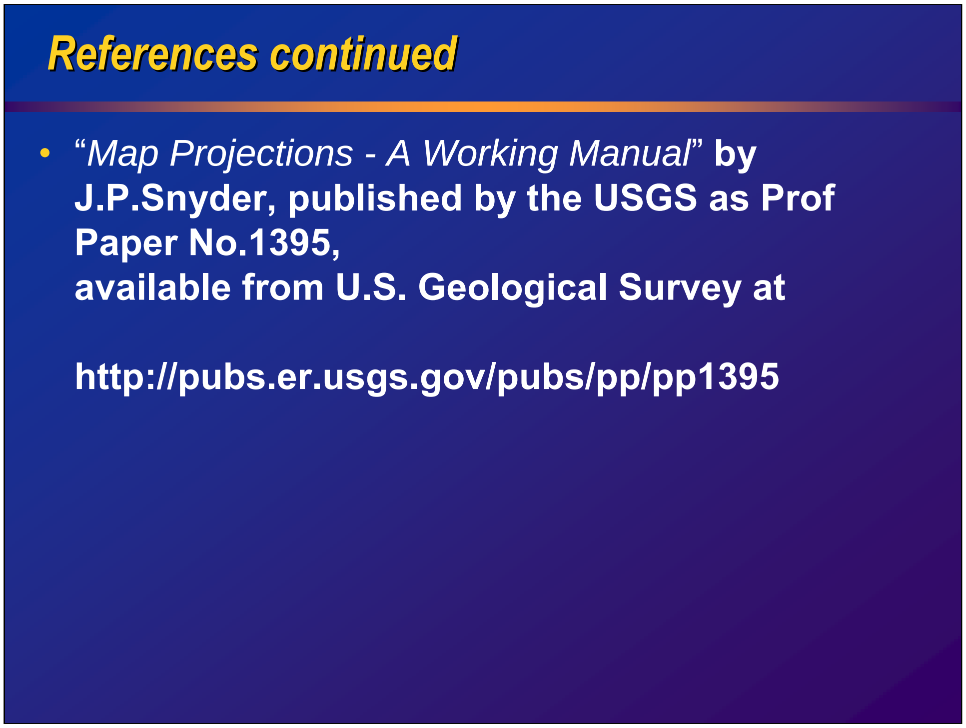
- *EPSG Guidance Note 7-2* and *EPSGv6.x* geodetic database, **download both free from OGP Surveying and Positioning Committee website hosted by OGP at**
  www.epsg.org
- "*Geodesy for the Layman*", U.S. National Imagery and Mapping Agency, **download free from NIMA's G&G website at:**
  http://earth-info.nga.mil/GandG/publications/geolay/toc.html
- APSG Geodesy Tutorial (ESRI PUG 2004 and 2007) **at: www.apsg.info**

References

The Surveying and Positioning Committee (S&P Committee) of the International Association of Oil and Gas Producers (OGP) was formerly known as the **European Petroleum Survey Group (EPSG).** The **OGP S&P Committee** continues to maintain the ***EPSG Geodetic Database*** and has committed to its continued development, maintenance and improvement. See more at http://www.epsg.org .

The US National Geospatial Intelligence Agency (NGA) was formerly known as the U.S. National Imagery and Mapping Agency (NIMA) and before that as the US Defense Mapping Agency (DMA). ***Geodesy for the Layman*** is available online at
http://earth-info.nga.mil/GandG/publications/geolay/toc.html

The **Americas Petroleum Survey Group (APSG)** provides an online PowerPoint ***User Tutorial*** for free download, under the "ESRI PUG 2004" section of the website.



References

"Map Projections - A Working Manual" by J.P.Snyder, published by the USGS as Prof Paper No.1395 is available for purchase from the USGS online at **http://pubs.er.usgs.gov/pubs/pp/pp1395**

Questions or comments,
Please?........