NATIONAL GEODETIC SURVEY

Datums, Heights and Geodesy

Central Chapter of the Professional Land Surveyors of Colorado
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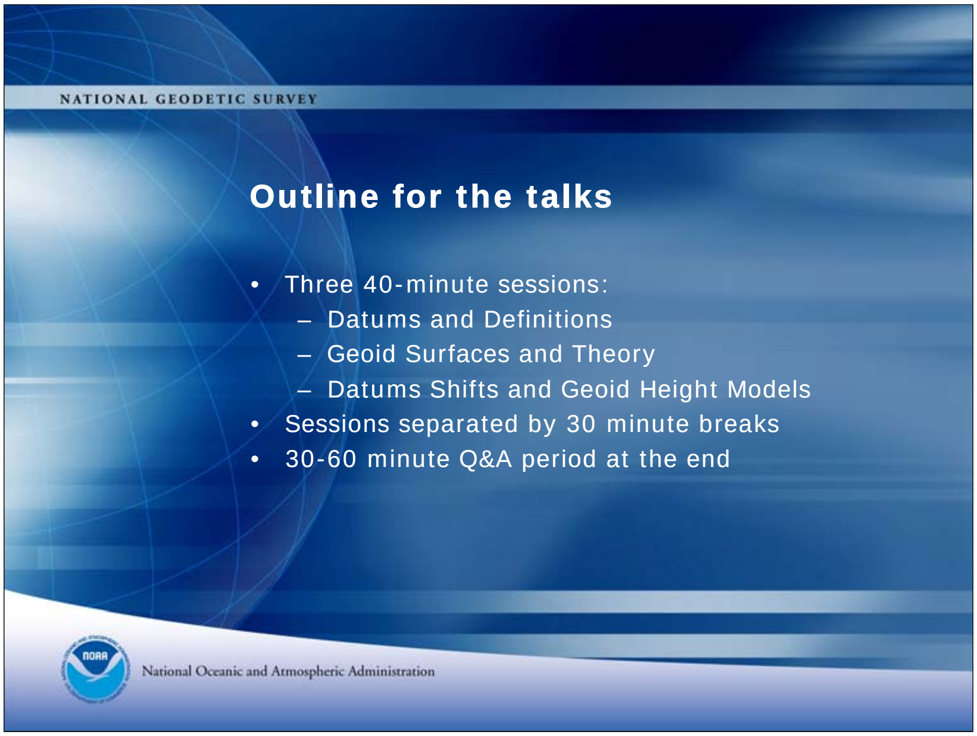
Daniel R. Roman
National Geodetic Survey
National Oceanic and Atmospheric Administration

National Oceanic and Atmospheric Administration



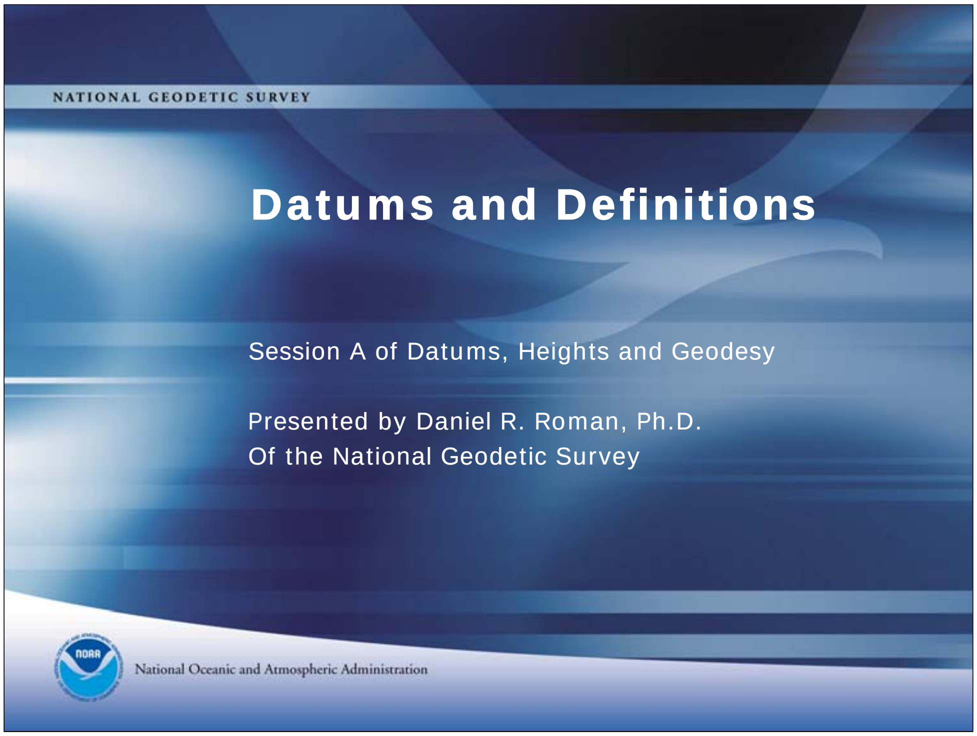
I will try to avoid excessive formulas and focus more on models of the math and relationships I'm describing.

General focus here is on the development of geoid height models to relate datums – not the use of these models in determining GPS-derived orthometric heights.

The first session will introduce a number of terms and clarify their meaning

The second describes how various surfaces are created

The last session covers the models available to teansform from one datum to another



-define datums - various surfaces from which "zero" is measured

-geoid is a vertical datum tied to MSL

-geoid height is ellipsoid height from specific ellipsoid to geoid

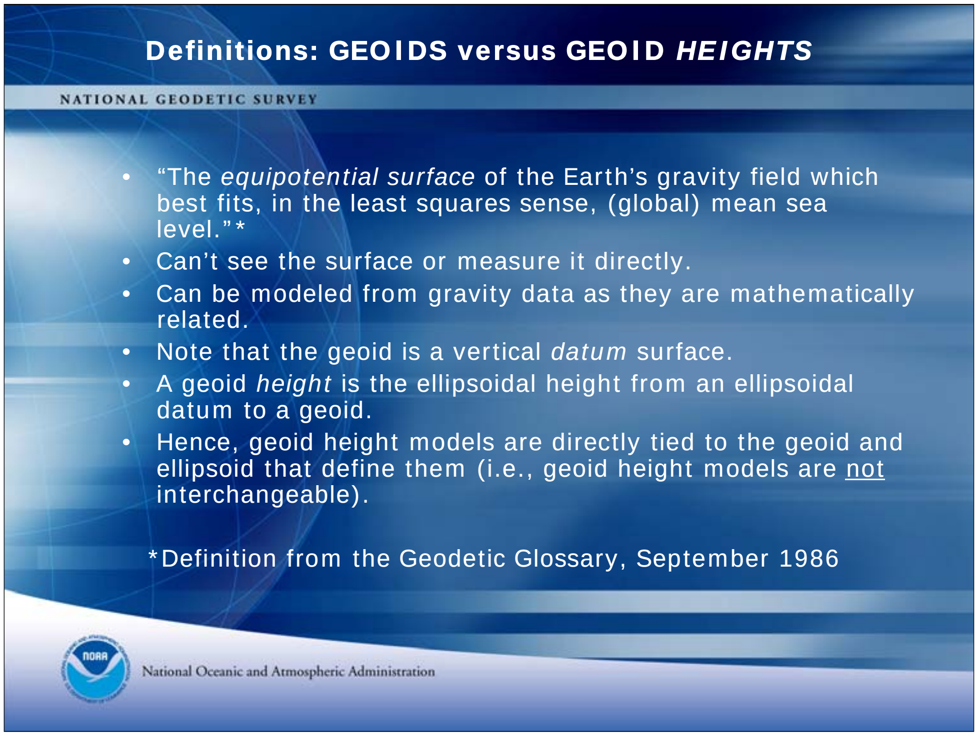
-types of geoid heights: gravimetric versus hybrid

-definition of ellipsoidal datums (a, e, GM, w)

-show development of rotational ellipsoid

Principal Vertical Datums in the U.S.A.

- North American Vertical Datum of 1988 (NAVD 88)
  - Principal vertical datum for CONUS/Alaska
  - Helmert Orthometric Heights
- National Geodetic Vertical Datum of 1929 (NGVD 29)
  - Superseded by NAVD 88
  - Normal Orthometric Heights
- International Great Lakes Datum of 1985 (IGLD 85)
  - Primarily of concern on the Great Lakes
- Earth Gravity Model of 1996 (EGM96)
  - Global reference model from NGA (aka NIMA aka DMA)
  - Tied to a lot of products such as SRTM DEM's
  - Soon to be superseded by EGM07, which will use GRACE data



-What does equipotential surface mean?

-If we could see or measure the geoid, this could be our vertical datum.

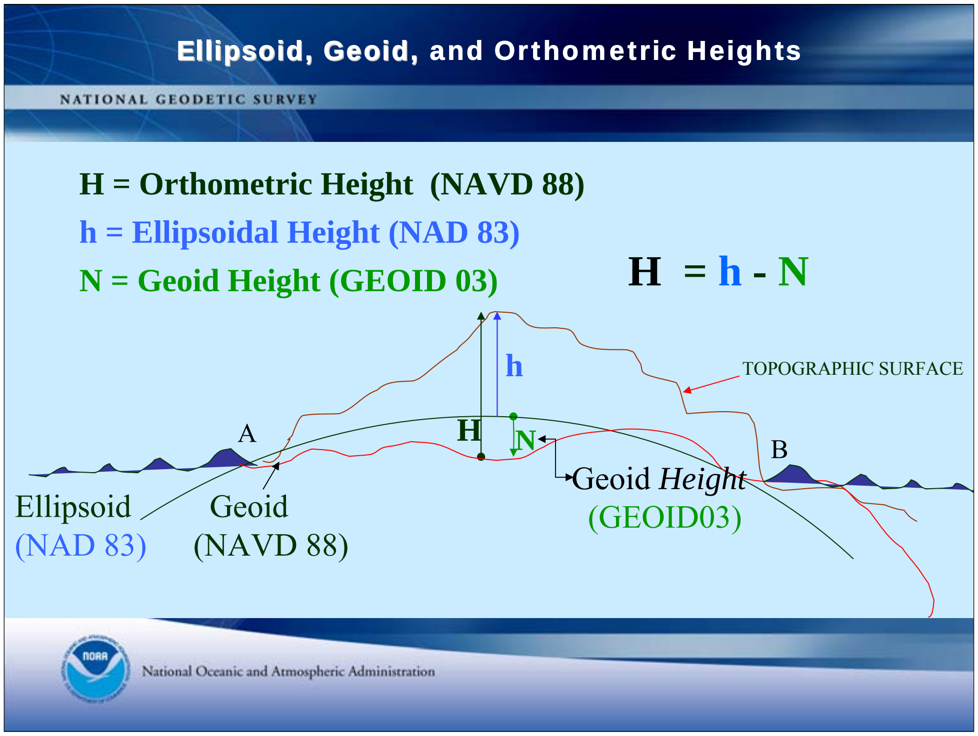
-It may be in the future, and we must plan for a transition.

-For now, we are dependant on leveling observations on the surface to create our datum.

-The leveling datum may or may not be a true equipotential surface (i.e., NAVD 88 =/ true geoid).

-use the geoid height models to transform between the ellipsoidal and vertical datums.

-the discussion of geoid height models will be reserved fr the datum transfrormation section as that is there intended use.



Orthometric height is the height on the surface above the geoid. But we can't measure from the geoid so we use leveling. The NAVD88 is defined from the control point, B, in Quebec. Because the ortho ht at A is computed from leveling observations, where error is modeled or estimated, it probably isn't right at the geoid, right at "sea level".

Our vertical datum is defined. We need a geoid that we can use that is relative to the vertical datum.

Note that in this picture the geoid is shown above the ellipsoid. In the continental United States, the geoid is actually below the ellipsoid, so the value of the geoid height is negative.

All Heights Based on Geopotential Number (C_P)

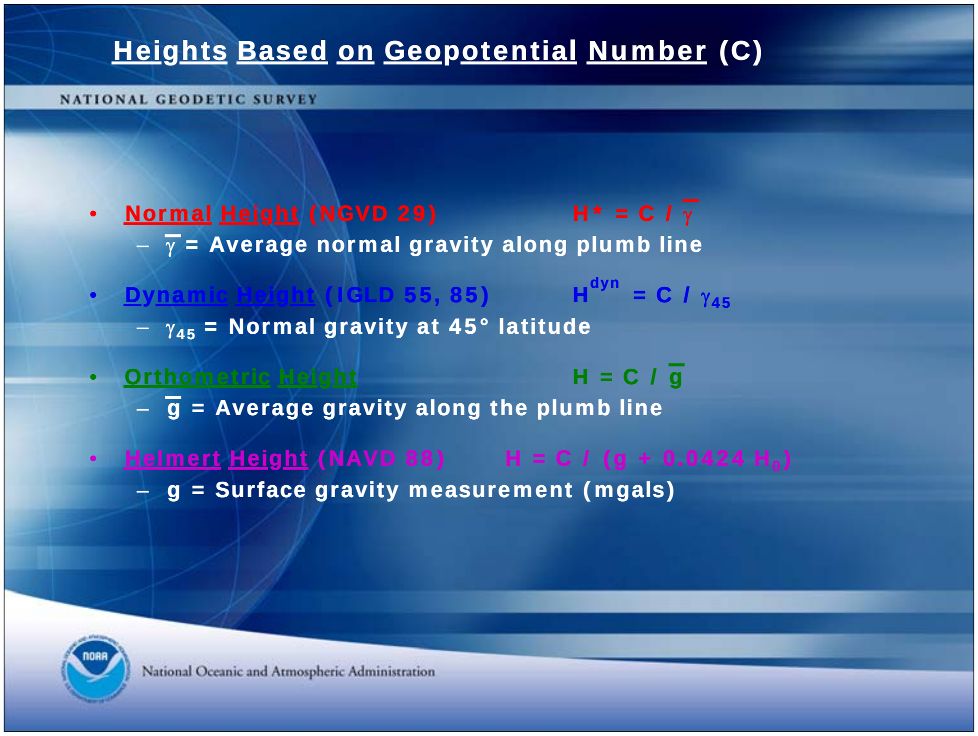
The geopotential number is the potential energy difference between two points

g = local gravity W_O = potential at datum (geoid) W_P = potential at point

$$\int_0^P g\,dn = W_0 - W_P = C_P$$

Why use Geopotential Number? - because if the GPN for two points are equal they are at the same potential and water will not flow between them

$$\Delta C_{b\text{-}a} = \sum_a^b h_i g_i$$



Heights based on Geopotential Number - all heights relate to geopotential number but with different components.

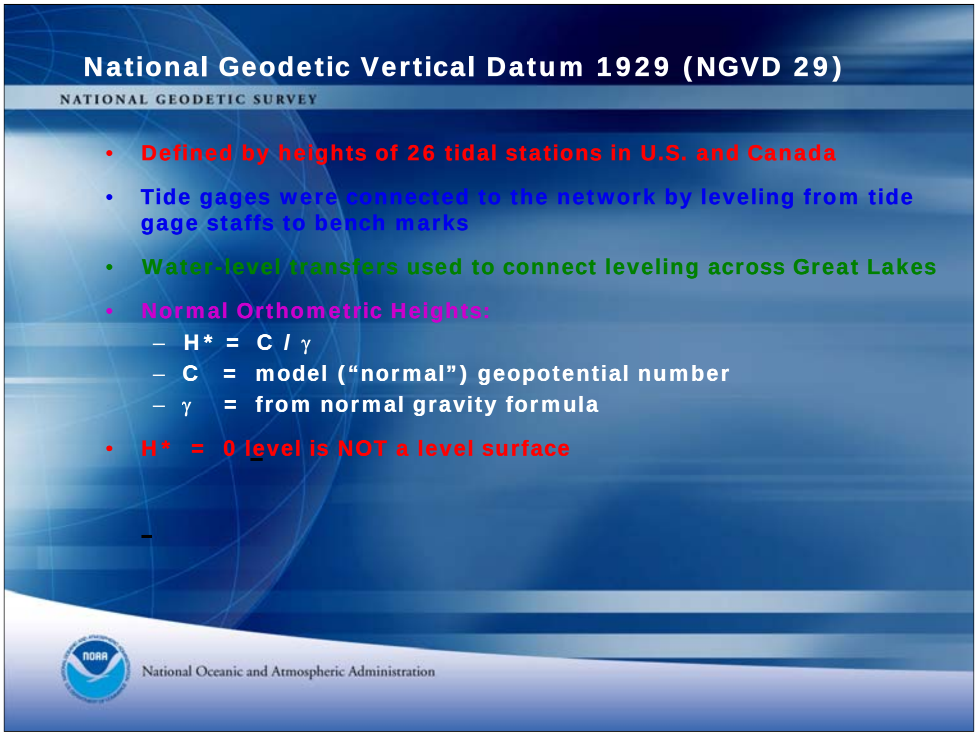
Normal Height - ☎ (gamma) = average normal gravity; value determined equal around equator then equal around lines of latitude.

NGVD29 did not have very much gravity information known in the U.S. or world; made simple model by latitude. Need accurate gravity data to fill equation for proper determination. H^* is not true orthometric height.

Dynamic Height - $☎_{45}$ is value of normal gravity determined at 45☜ latitude. Designed for use by IGLD55, 85 International Great Lakes Datum. Orthometric Height - g average gravity along plumb line; definition is true but impractical to obtain - measurements obtained through bored hole with gravity meter due to layer changes.

Helmert Height - g is surface gravity measurement; provides very close approximation of height above geoid and a model with 3 cm differences (better than previous 2 m model) - achievable - practical.

Helmert - Geodesist 1860's - designed formula based upon a surface gravity measurement which provides an assumption of the density of underlying rock. The average 0.0424 interpretation of rock density is good across most of the U.S. and provides value in equation used in iterative determination of H NAVD88.



Vertical Datums - heights relative to defined datum.

NGVD 29 - 0 height (mean sea level) - not true level surface due to inherent problems; normal heights (averaged gravity). NGVD29 "warped" to fit 26 tide gages; disparity between Pacific and Atlantic Oceans, mean sea level … geoid.

Individual tide gages are not the same; affected by sea surface topography due to currents, salinity, temperature, weather patterns, etc.; USC&GS forced heights to tide gages creating biases; knew bad but presented a fair approximation.

Normal heights + bias … level surface.

First-Order Leveling Network NGVD 29

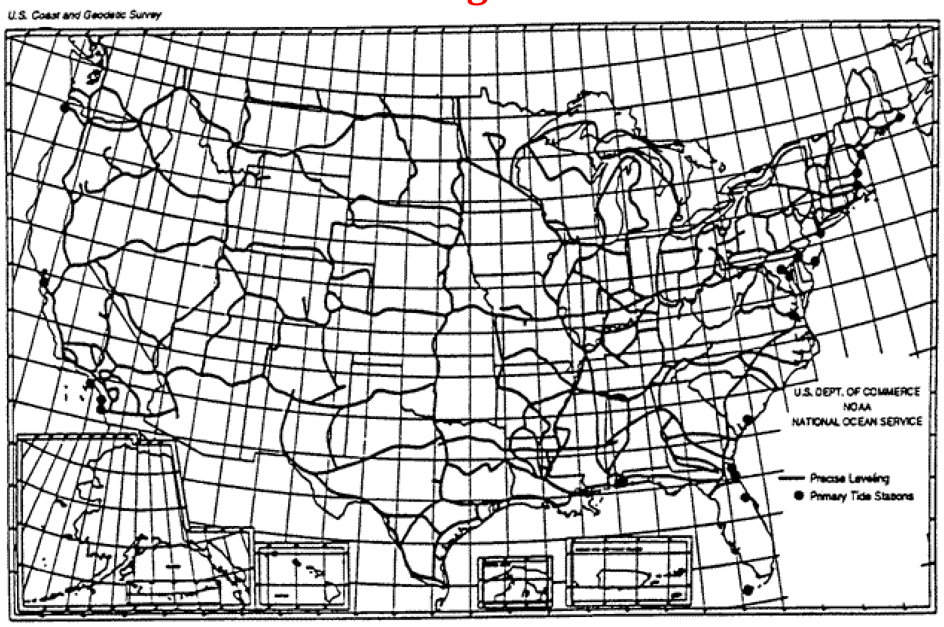
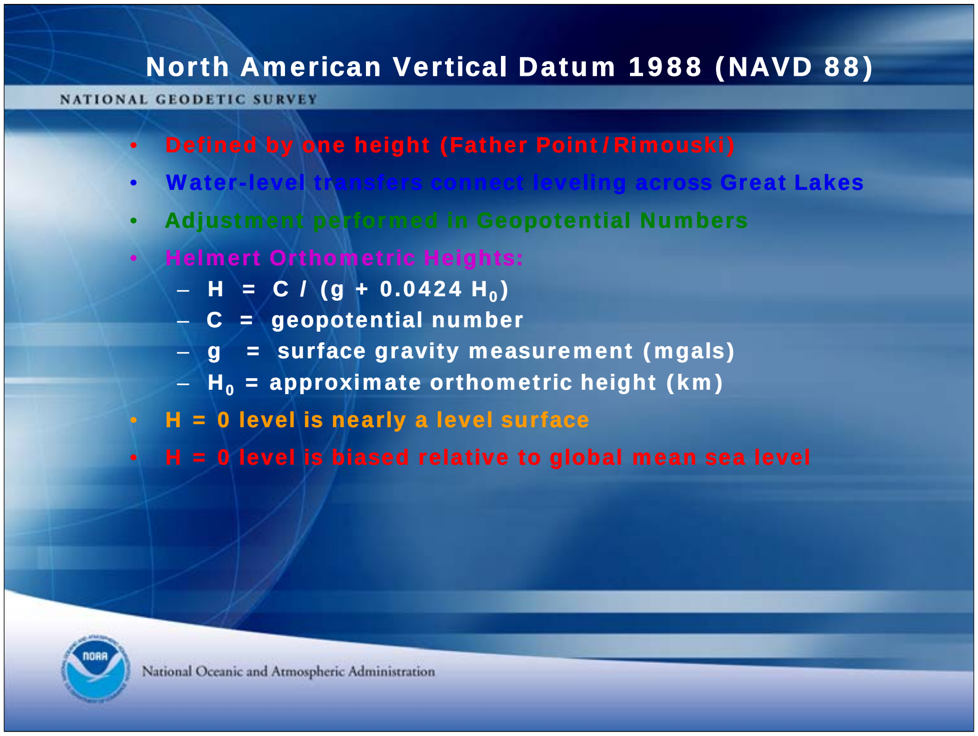


Figure 1. First-order vertical control used in 1929 adjustment.

Levels and tide station connections included in NGVD29.



NAVD 88 - 0 height - took the opportunity to produce a close approximation to a level surface within ± 3 cm; only one bias introduced; defining the 0 height at Father Point, Rimouski, Quebec, Canada.

Problems - height based on Father Point, Rimouski - minimizes changes to USGS maps but adds about 30 cm error relative to global mean sea level at Father Point, Rimouski.

Utilizes good gravimetric coverage of the U.S.

Vertical Control Network NAVD 88

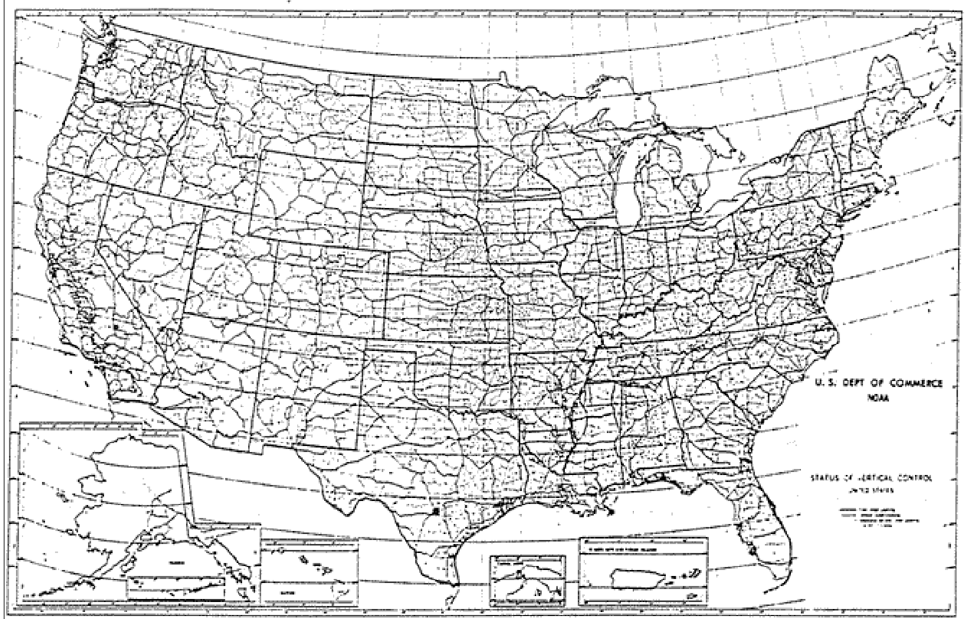


Figure 3. Vertical control used in 1988 adjustment.

Levels and only the one connection to tide gage included in NAVD88.

NGVD 29 Versus NAVD 88

	NGVD 29	**NAVD 88**
Datum Considerations:		
• Defining Height(s)	26 Local MSL	1 Local MSL
• Tidal Epoch	Various	1960-78 (18.6 years)
Treatment of Leveling Data:		
• Gravity Correction	Ortho Correction (normal gravity)	Geopotential Nos. (observed gravity)
• Other Corrections	Level, Rod, Temp.	Level, Rod, Astro, Temp, Magnetic, and Refraction
Adjustments Considerations:		
• Method	Least-squares	Least-squares
• Technique	Condition Eq.	Observation Eq.
• Units of Measure	Meters	Geopotential Units
• Observation Type	Links Between Junction Points	Height Differences Between Adjacent BMs

Differences between NGVD29 and NAVD88 - summation of defining characteristics.

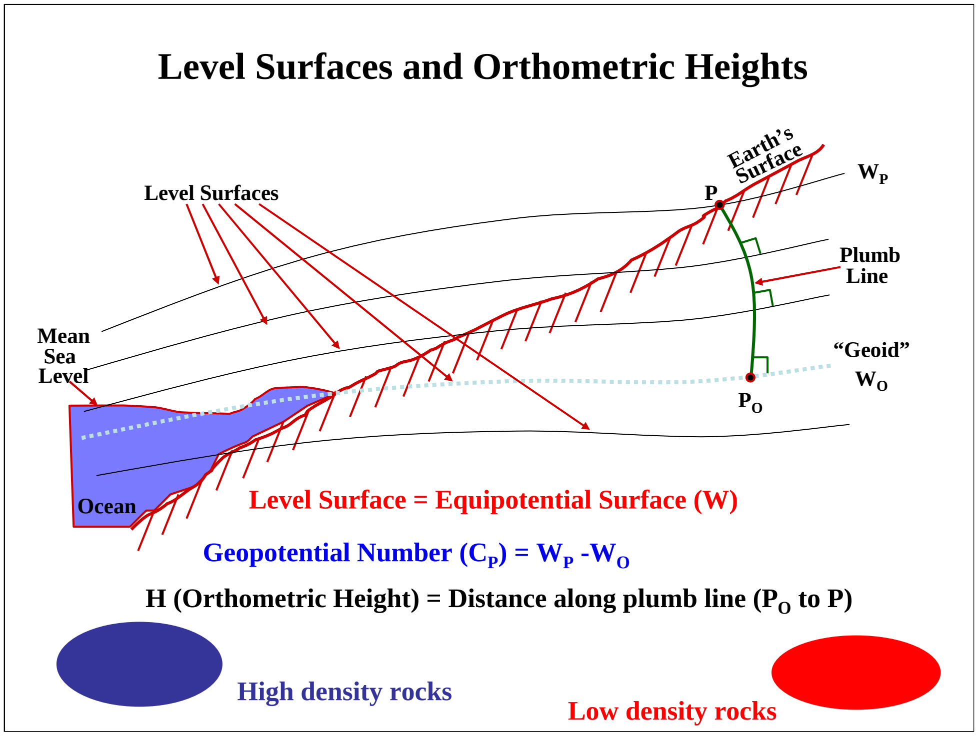
Basis for defining heights; biases and tidal epochs used, treatment of data, adjustment considerations, adjustment statistics, and published information.

NGVD 29 Versus NAVD 88 (continued)

Adjustments Statistics :	NGVD 29	NAVD 88
• No. of Bench Marks	100,000 (est)	450,000 (US only)
• Km of Leveling Data	75,159 (US) 31,565 (Canada)	1,001,500

Published Information:		
• Orthometric Height Type	Normal	Helmert
• Orthometric Height Units	Meters	Meters
• Gravity Value	Normal	"Actual"

Differences between NGVD29 and NAVD88 - summation of defining characteristics.



Level surfaces - imagine earth standing still - ocean standing still; no effects such as currents, tides, winds; except for slight undulations created by gravity effects = level surface.

Geoid is this level surface relating to today's mean sea level surface - this does not truly coincide with mean sea level because of the non-averaging effects of currents, tides, water temperatures, salinity, weather, solar/lunar cycle, etc. The geoid is a best fit mean sea level surface.

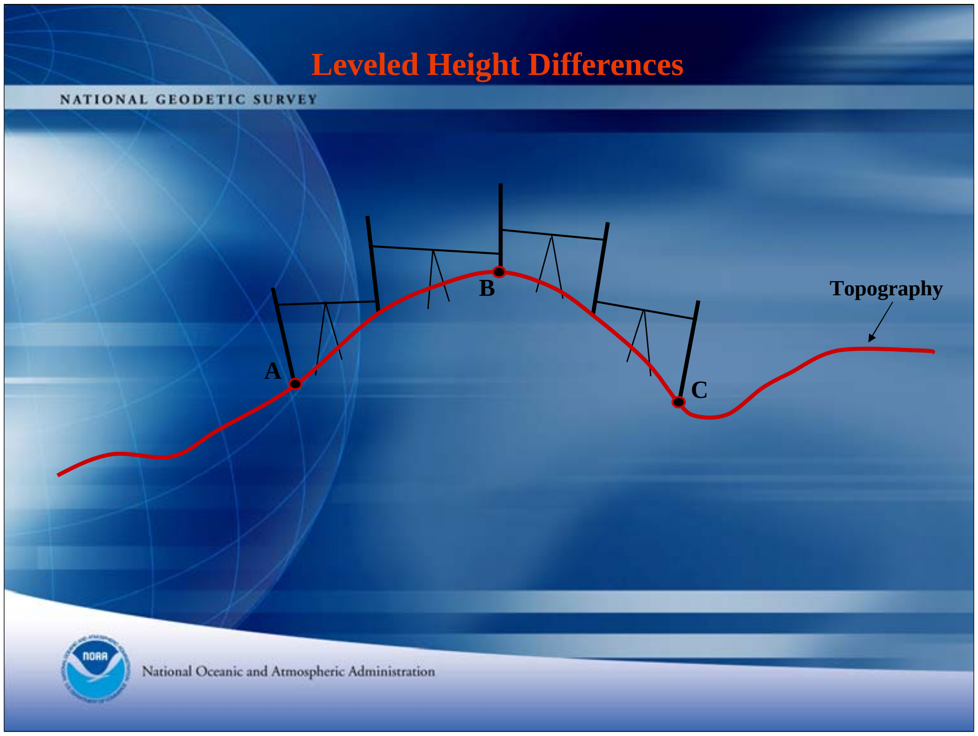
Equipotential surfaces - add or subtract water and level surface changes parallel to previous surface = infinite number of possible level surfaces. Each equipotential surface has one distinct potential quantity along its surface.

Point on earth's surface is the level surface parallel to the geoid achieved by adding or subtracting potential. Lines don't appear parallel; they are based on the gravity field and are affected by mass pluses and minuses.

Geopotential number is the numerical difference between two different equipotential surfaces. W = potential along a level surface. C_P = geopotential number at a point.

Plumb line (over exaggerated in drawing) - is a curved distance due to effects of direction of gravity- known as deflection of the vertical.

Orthometric height is exactly the distance along this curved plumb line between the geoid and point on the earth's surface. We can make close approximations but to be exact we would need to measure gravity along this line requiring a bored hole which is impractical.

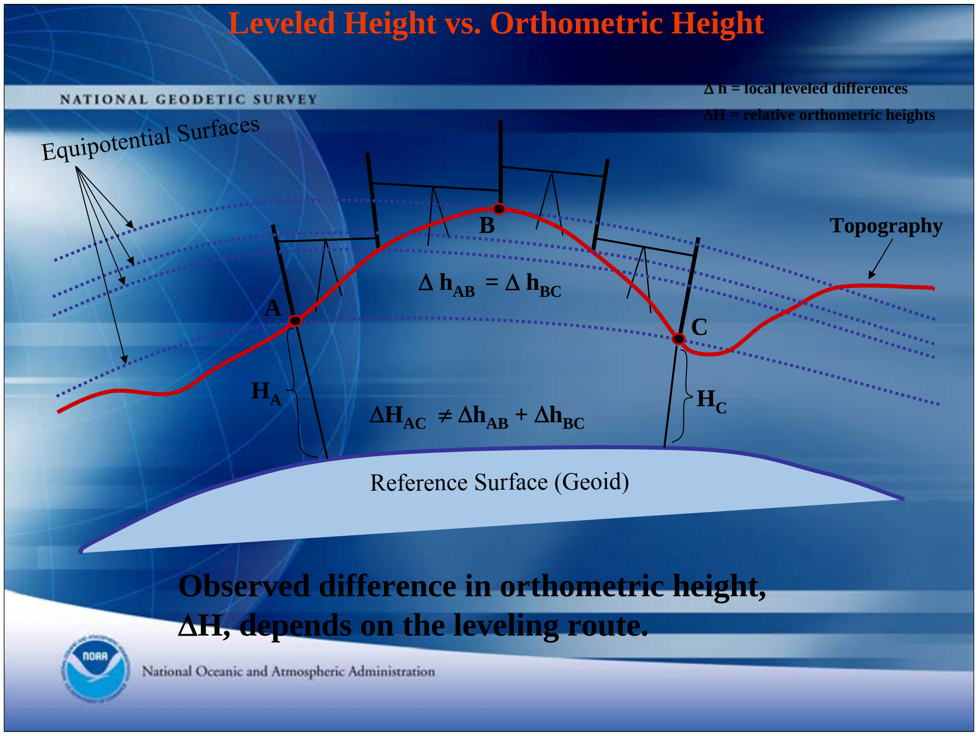


Begin our understanding of orthometric heights.

Heights & Datums - traditionally orthometric heights meant above sea level. Now we must be aware of factors affecting our understanding and use of height interpretations.

Determining elevation differences through use of conventional leveling procedures. Conventional spirit-leveled height from points A to B and B to C.

Differential leveling surveys, being a “piecewise” metric measurement technique, accumulate local height differences (dh).



Combining what we've discussed. For illustration, let's assume the same equipotential (level) surface runs through points A and C. As discussed, there are an infinite number of level surfaces; another illustrated through point B.

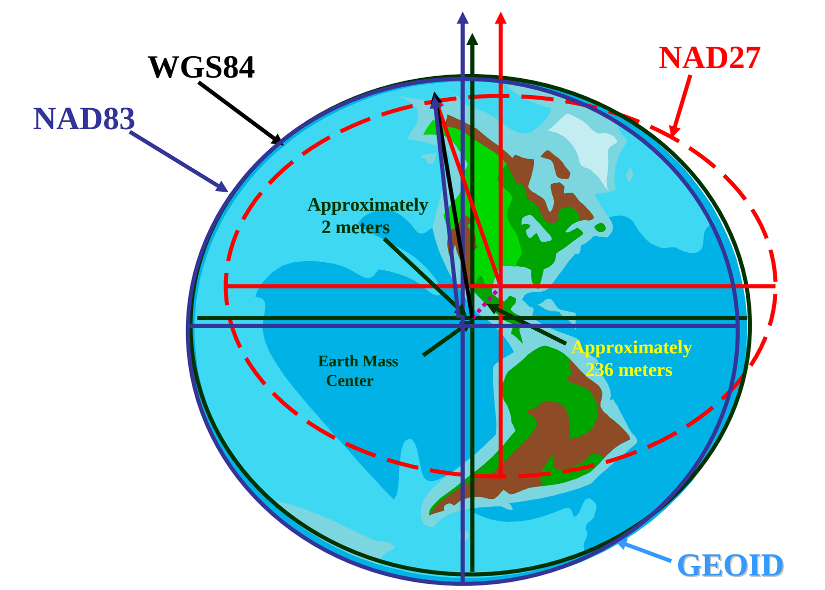
Conventional spirit-leveled height from points A to B and B to C. Differential leveling surveys, being a "piecewise" metric measurement technique, accumulate local height differences (dh). Leveled height difference from point A to B equals the leveled height difference from point B to C; $(dh_{AB}) = (dh_{BC})$.

The sum of these leveled differences is not, however, equal to the difference in orthometric height (dH) between two bench marks A and C. This is due to the non-parallelism of level surfaces $(dH_{AC}) \neq (dh_{AB}) + (dh_{BC})$.

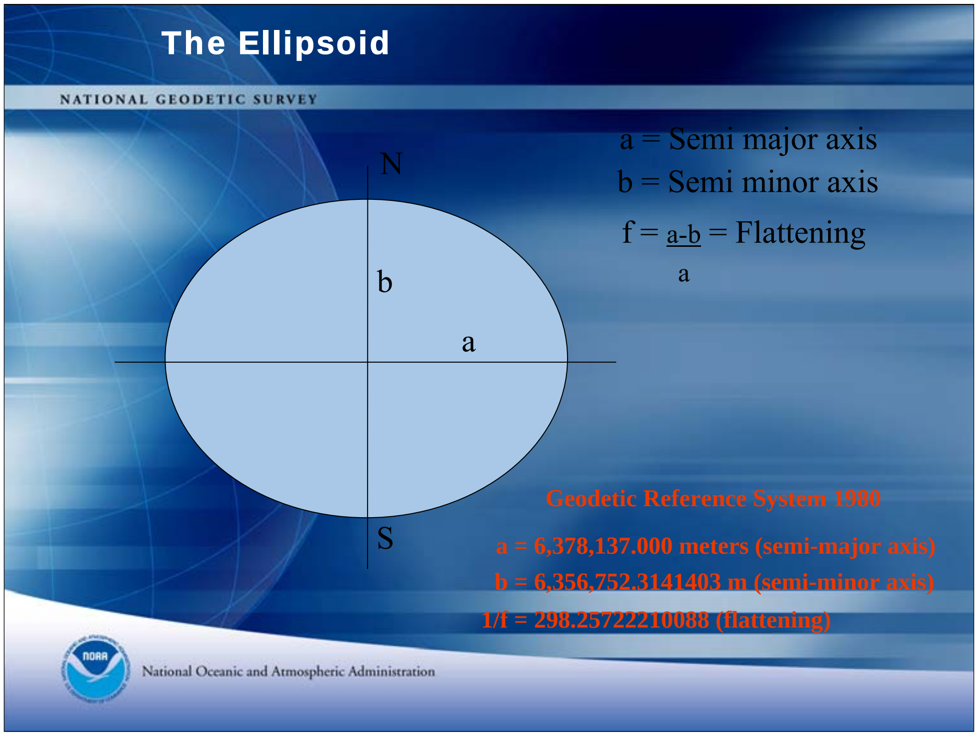
The difference between leveled height (dh_{AC}) and relative orthometric height (dH_{AC}) is orthometric correction. The difference is usually greater in mountainous regions where level surfaces exhibit much greater local warping due to more pronounced changes in local gravity. The orthometric height is determined by the distance along the plumb line from the reference surface (Geoid) to the point.

Principal Reference Ellipsoids in the U.S.A

- North American Datum of 1983 (NAD 83)
  - Uses a GRS-80 ellipsoid shell (the standard)
  - Coordinates compatible with GPS observations
  - System hasn't changed over time
- North American Datum of 1927 (NAD 27)
  - Regional ellipsoid – not global!
  - Superseded by NAD 83
- World Geodetic System of 1984
  - Developed by NGA (aka NIMA aka DMA)
  - Several versions since first introduced based on GPS week
  - Very similar to the evolution of the ITRF models
  - Essentially the same GRS-80 shell but a different geocenter
  - Offset is nearly 2.2 meters from NAD 83



WGS84 and NAD83 share the GRS80 ellipsoid but the origin differs by about 2m
NAD27 uses the Clark spheroid of 1866, the origin is 236 m from WGS84



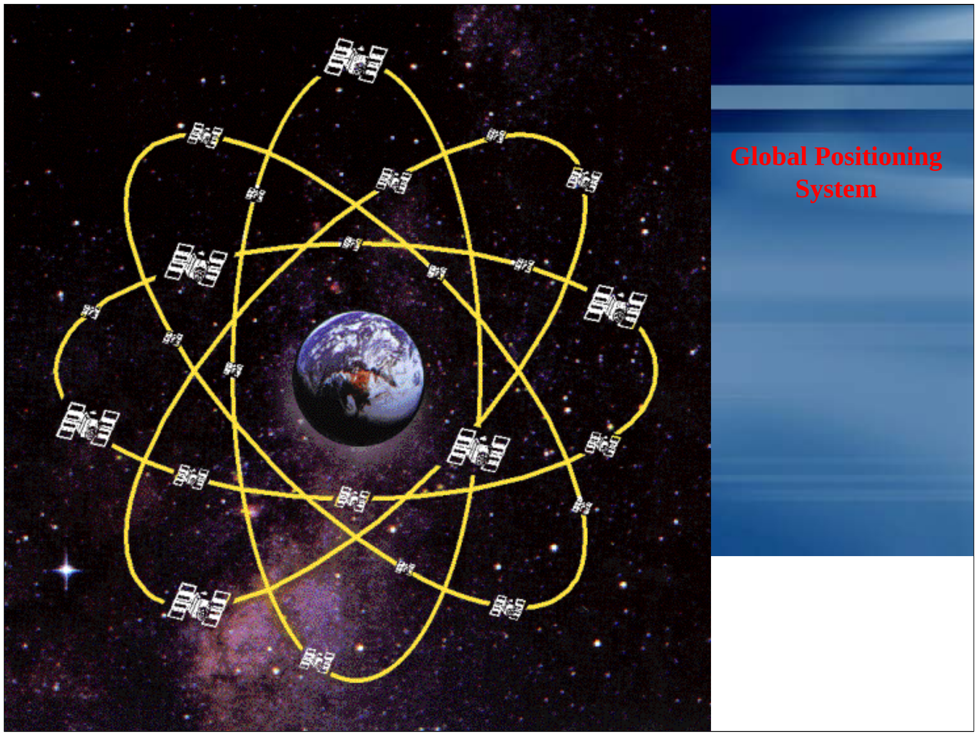
Ellipsoid - a smooth mathematical surface which resembles a squashed sphere that is used to represent the earth's surface.

NAD83 or WGS84 - need to know defined datum in software. The point remains the same; identify and work with reference ellipsoid.

Defining parameters for the size and shape of these two ellipsoids are equal at the equator and mm difference at the poles. The definition of the origin is the noticeable difference. The origin for NAD83 is defined at a point known to be 1 to 2 meters from the center of mass. The origin for WGS84 moves with updated information; currently about 5 cm relative to ITRF94. This latest change taking place in late 1996 or early 1997.

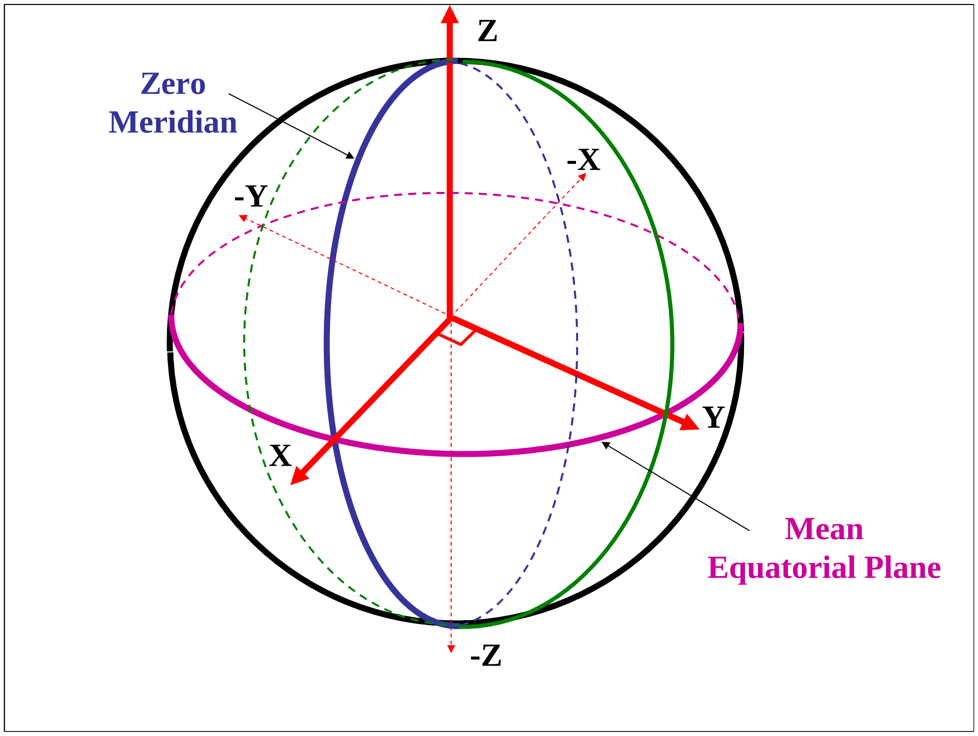
There are no WGS84 coordinates because of the changes in its reference origin. Surveys must always be traceable and consistent.

Assigning the Earth's GM value and the rotation rate (omega) and rotating around the polar axis yields a rotational ellipsoid of reference having a normal gravity field (gamma).



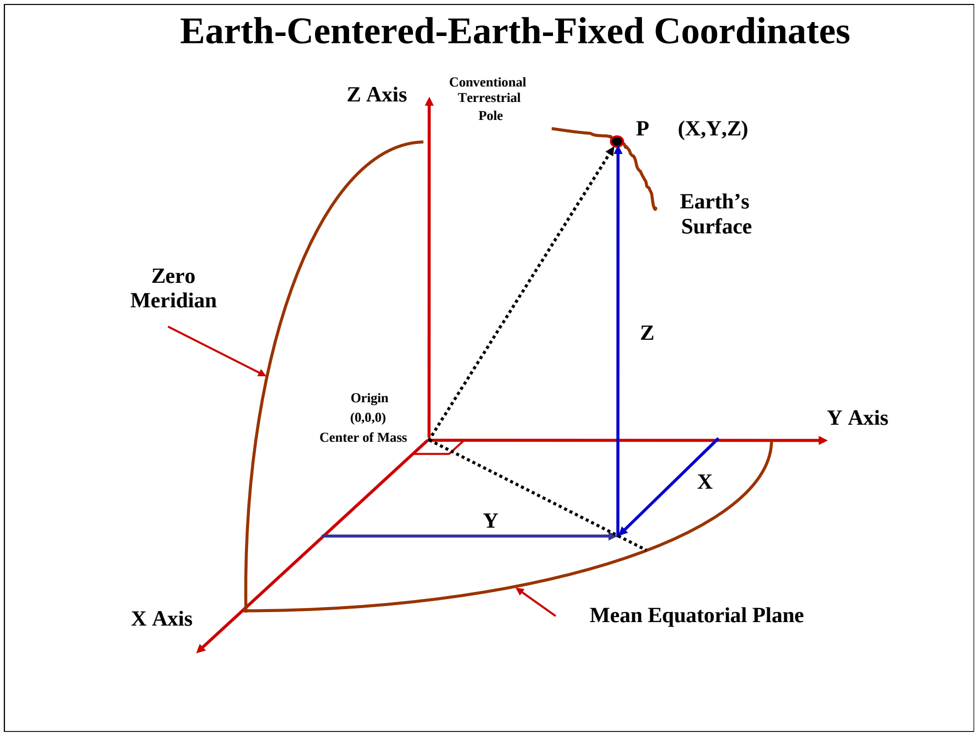
This illustration depicts the relationship of the earth with the space based GPS.

Let’s explore using GPS to derive heights at the 2 to 5 cm level of accuracy from interpreting information from satellite signals originating 20,183 km (12,500 miles) in space.



GPS Coordinate System - works with X, Y, Z coordinate frame based on center of mass Earth-Centered-Earth-Fixed (ECEF) coordinate system; changed into ellipsoidal latitude, longitude, and height through transformation.

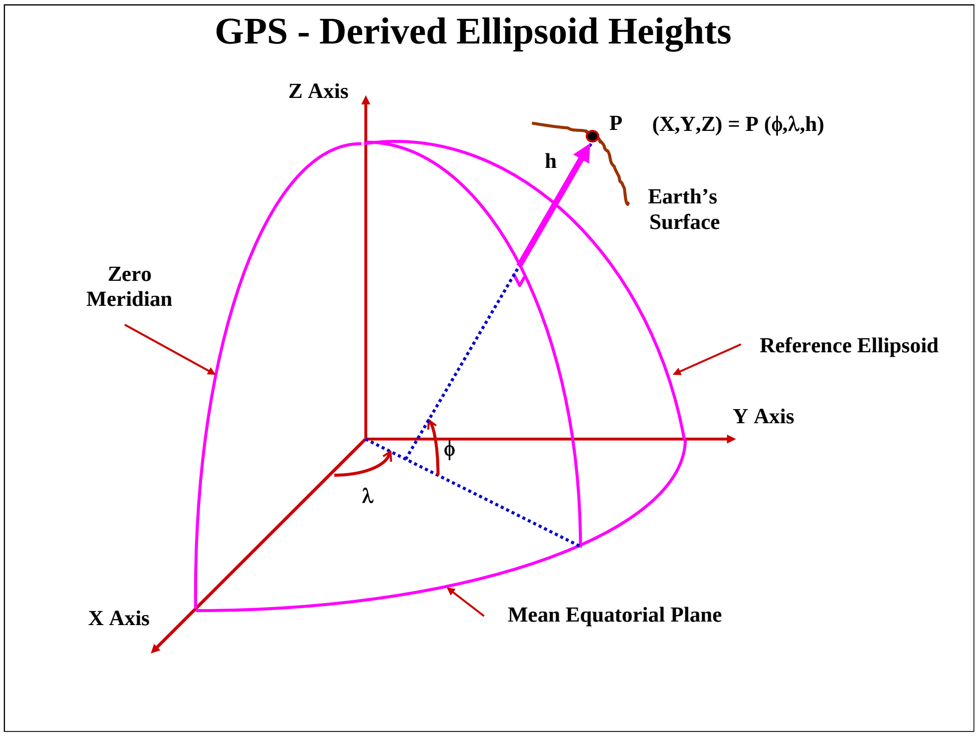
Cartesian Coordinate System.



Point on the Earth's surface positionally defined with an X, Y, Z coordinate.

The distance along the Z axis is not a height.

Height information is not apparent in this system.



Curvilinear Coordinate System

Same point on Earth's surface positionally defined by latitude, longitude and ellipsoid height.

Ellipsoid height is the height of the point relative to the reference ellipsoid surface.

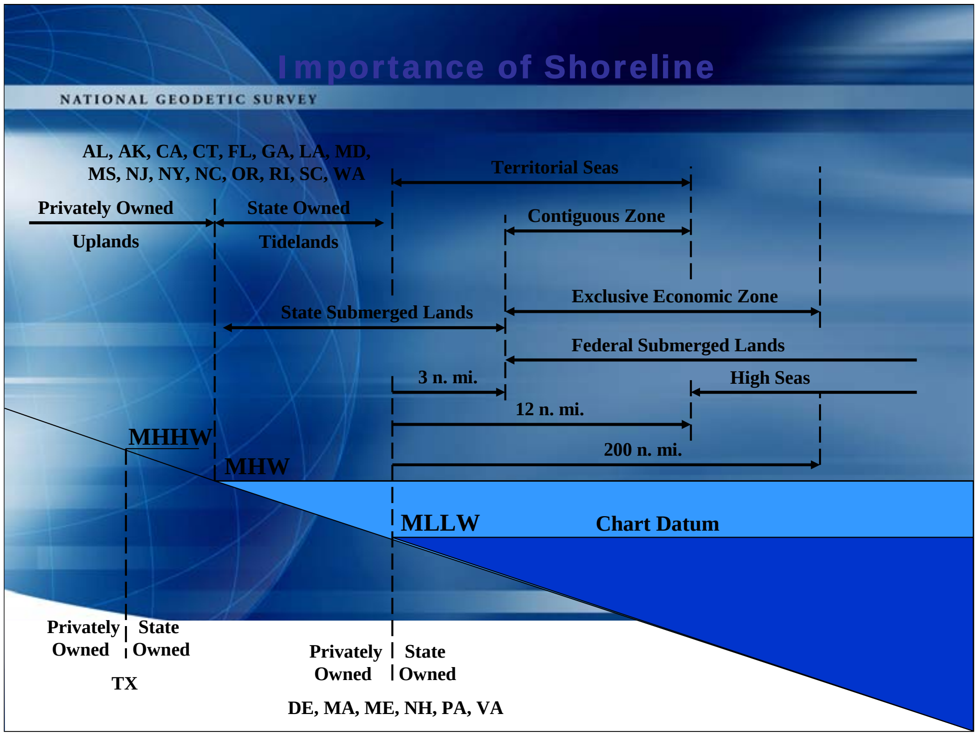
Same point can be positionally defined as and X, Y, Z or latitude, longitude, ellipsoid height.

Tidal Datums

- Heights Measured Above Local Mean Sea Level
- National Tidal Datum epoch; 19 year series
- Encompasses all significant tidal periods including 18.6 year period for regression of Moon's nodes
- Averages out nearly all meteorological, hydrological, and oceanographic variability
- Leveling is used to determine relationship between bench marks and tidal gauges

Sea level heights - we want heights relative to mean sea level to equal that of the geoid but we cannot achieve this goal; always differences between levels and local mean sea level..

National Tidal Datum epoch - 19 year period of averaging phases such as lower low water almost eliminates effects within ocean caused by lunar phases, meteorological, hydrological, and oceanographic variability.



State define boundaries by statute which varies around the United States.

Changes in sea level will affect these boundaries.

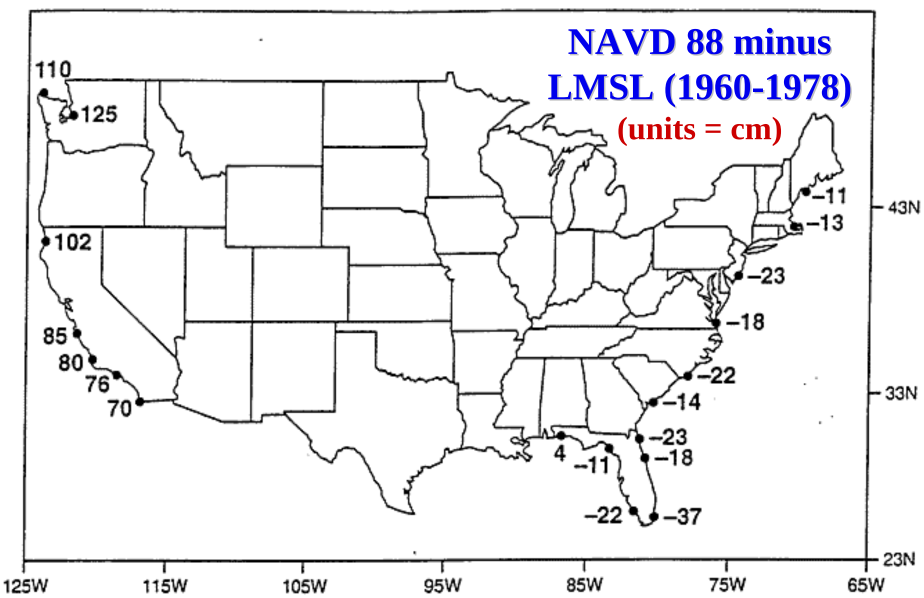
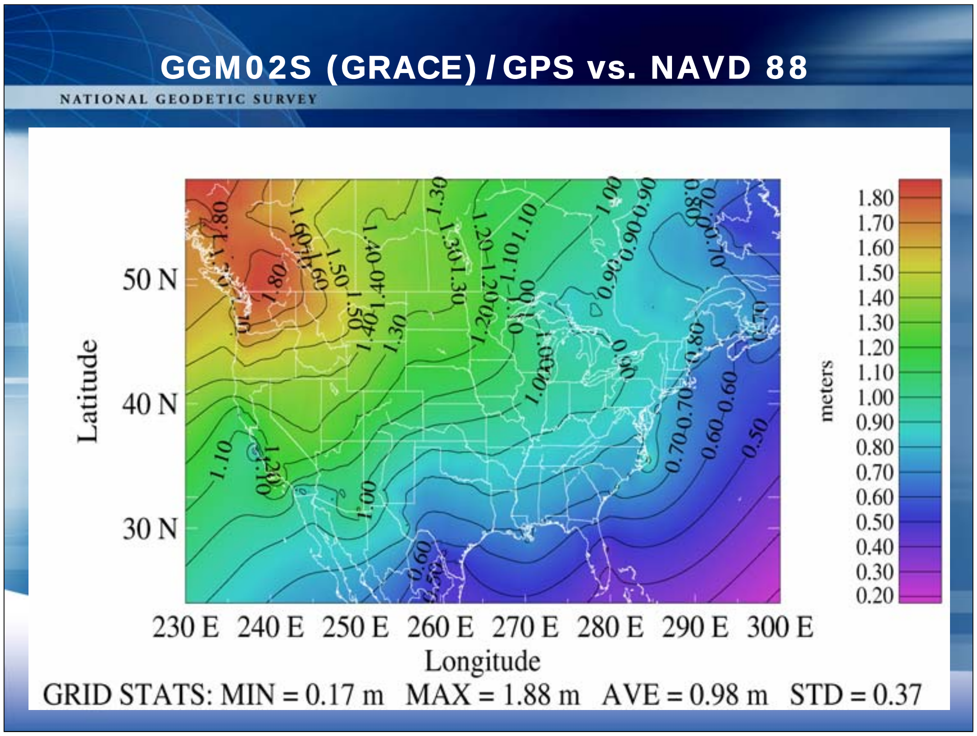


Figure 9. Height differences between NAVD 88 and heights of tidal benchmarks above LMSL (epoch 1960-78) (units = cm).

Note differences along coasts and that there is a slope to LMSL (local mean sea level).



The above figure highlights the long wavelength (greater then 660 km full wavelength) differences between GPS/leveling derived from a GGM02S geoid heights & GPS-derived ellipsoidal heights and leveled heights above the NAVD 88 datum. The expectation is that the GPS/leveling is cm-level accurate and that the above signal represents error in the NAVD 88 datum.

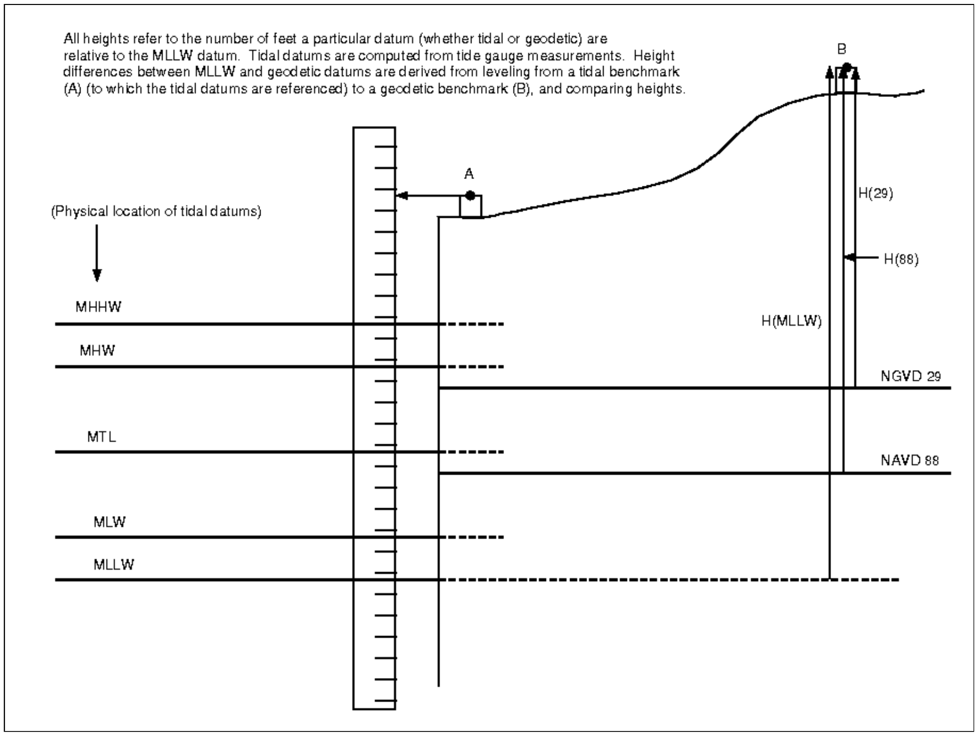


Chart illustrating relationship of tidal information, vertical datums, and bench marks.

Note that neither NAVD 88 or NGVD 29 intersect at the MTL. This because of dynamic topography issues as well as bias and datum errors with respect to global MSL.

QUESTIONS?

Geoid Research Team:

- Dr. Daniel R. Roman, research geodesist
  dan.roman@noaa.gov
- Dr. Yan Ming Wang, research geodesist
  yan.wang@noaa.gov
- Jarir Saleh, ERT contractor, gravity database analysis
- William Waickman, programming & database access
- Ajit Sing, Datum Transformation Expert
- Website: http://www.ngs.noaa.gov/GEOID/
- Phone: 301-713-3202