Introduction

The USAF declared the Global Positioning System (GPS) “operational” in 1994. This was the biggest game changer in the history of surveying.

Presently we have GPS, Glonass, Galileo and Compass (Beidu) all referred to as the Global Navigation Satellite System (GNSS).

GNSS is shrinking the world - It is more important than ever to adopt universal datums for integrating geo-spatial communities.
Introduction

- Obtaining accurate measurements with GNSS is overshadowed by the importance and consequences of the positions we publish.

TERMINOLOGY

- Datum: A mathematical model defined by parameters that determine its origin, scale, and orientation and used to describe the spatial relationship of points. A datum can be 1, 2, 3 or 4 dimensional.

- Reference Frame (Reference System): A datum is realized by establishing coordinates on points (monuments) in the world which provides access to the datum. The introduction of new measurements and adjustments is a new realization of the datum. New adjustments are used to improve the accuracy of points in an absolute sense relative to the datum, and locally relative to other points.

- A set of station coordinates infers a particular realization of a reference frame for a datum.

TERMINOLOGY

1. Datum Recovery: The acquisition of a datum through measured connections to monuments referencing the datum, or applying a model or a transformation to move from one datum or realization to another.

   - A report containing a qualitative and quantitative analysis of the recovery is necessary so others can make an assessment and “follow in your footsteps”.

ACRONYMS

ITRF08 / IGS08
GRS80
NAD27
CSRN
WGS84
HARN
NAD83

NSRS
CORS
HPGN
NAVD88
GRS80
NAD83
Acronyms

- **Datums**
  - ITRS: International Terrestrial Reference System (geocentric)
  - NAD27: North American Datum 1927 (horizontal system)
  - NAD83: North American Datum 1983 (not geocentric)
  - NAVD88: North American Vertical Datum 1988
  - NGVD29: National Geodetic Vertical Datum 1929
  - WGS84: World Geodetic System 1984 (DOD) (equivalent to ITRF93)
- **Reference Systems**
  - CSRN: California Spatial Reference Network (California’s NSRS) (see PRC)
  - HARN: High Accuracy Reference Network (NAVD88)
  - HPGN: High Precision Geodetic Network (CA’s HARN, first GPS in 1991)
  - HPGN-D: Densification of the High Precision Geodetic Network
  - IGS: International GNSS Service
  - ITRF: International Terrestrial Reference Frame
  - NGRS: National Geodetic Reference System (old name)
  - NSRS: National Spatial Reference System (new name for NGRS)
  - VLBI: Very Long Baseline Interferometry (world network)
- **Projections**
  - SPC: State Plane Coordinate System (Lambert or Mercator Projections)
  - UTM: Universal Transverse Mercator (world coordinate system)

Agenda: Geodetic Datums

- **1D: Vertical**
  - Geoid
  - Tidal Datums
    - NGVD29
    - NAVD88
- **2D: Horizontal**
  - NAD27
  - NAD83
- **3D: Geometric**
  - NAD83
  - WGS84
  - ITRF/IGS (4D)

Vertical Datums

- **1D: Vertical**
  - Geoid – Global Mean Sea Level Concept
  - Tidal Datums
    - NGVD29 - National Geodetic Vertical Datum of 1929
    - NAVD88 - North American Vertical Datum of 1988

Geoid – An Elusive Datum

- The Geoid: An equal-potential surface approximating global mean sea level.
Geoid – An Elusive Surface

- Equal-Potential Surface is a surface where the force of gravity is everywhere equal. There are an infinite number of equal-potential surfaces. These surfaces are undulating due to the non-homogenous nature of the mass of the planet.

- The Geoid is defined as that particular equal-potential surface that represents global mean sea level, as if it were extended into the land masses and unaffected by exo-planetary gravitational forces (water does not flow).

Geoid – an analogy

- In a Galaxy far far away... you discover a world similar to the earth,
  • completely covered with water,
  • it doesn’t rotate,
  • there is no sun and moon,
  • no tides, no currents,
  • the water is at rest, and then it suddenly freezes over.

- You setup your instrument on the ice surface and run levels, and every where you run across the planet you find the surface elevation to be the same. That undulating surface is an equal-potential surface.

- Back on the Earth, the Geoid is a particular equal-potential surface defined as global mean sea level.

Geoid – An Elusive Surface

- Heights measured with trigonometric and differential leveling methods are Orthometric Heights.

- Orthometric Heights (elevations) are normal (perpendicular) to the geoid surface and represent the length of the gravity vector from a point on the surface of the earth to the geoid.

- The zero surface of NGVD29 and NAVD88 was intended to approximate the geoid.

Geoid

- Gravimetric measurements are used to define the surface of the geoid.

- Geoid surface varies (undulates) across the earth because of changing gravity forces due to the size and densities of the land masses.

- Difference between the geoid and an ellipsoidal surface is called the geoid separation (N).
**ELLIPSOID - GEOID RELATIONSHIP**

Orthometric Heights are modeled by applying geoid separations (N) to ellipsoid heights (h) to obtain orthometric heights (H).

\[ H = \text{Orthometric Height (NAVD88)} \]
\[ h = \text{Ellipsoidal Height (NAD83)} \]
\[ N = \text{Geoid Height} \]

\[ H = h - N \]

**Geoid Model**

- Geoid Models define the heights or separation between the geoid and ellipsoid surface at a given location.

- The geoid-ellipsoid separations are interpolated from a grid data base stored in binary and ascii files. Data for the present Geoid12A Model for California is contained in the file “g2012au5.bin” available at the NGS:

- Input is NAD83 latitude and longitude. Do not use NAD27 (300’ difference).

- Geoid12A is the present hybrid geoid model release in July 2012 to estimate the NAVD88 surface relative to the NAD83(2011) ellipsoid surface.

**Geoid Model (continued)**

- Geoid12A was preceded by Geoid09, Geoid03, Geoid99, Geoid 96, Geoid 93, and Geoid 90.

- The GEOID12A model like 09, 03, 99, and 96 are hybrid models. The hybrid model is based on a gravity model; however, it is modified to best fit NAVD88 benchmarks with measured NAD83 ellipsoid heights.

- Geoid09 is the former hybrid geoid model developed by the NGS to estimate the NAVD88 surface relative to the NAD83(2007) ellipsoid surface.

- GEOID09 model was based on the 2007 Adjustment of NAD83 which re-adjusted and harmonized the High Accuracy Reference Networks (HARN) in the 48 continental states. GEOID09 is to be used with NAD83 (2007.00) ellipsoid heights which are not the same as NAD83(2011) ellipsoid heights.

- Geoid09 has an estimated 2-3 cm accuracy (one sigma) in regions with GNSS measurements on NAVD88 Bench Marks. According to the NGS, a relative accuracy of about 1 to 2 part-per-million, or better is expected in areas with sparse coverage.
Example: EH’s using Geoid09 & Geoid99
A look at the relationship $h = H + N$: Measured EH’s v. Computed EH’s get better with new adjustments and better geoid models

<table>
<thead>
<tr>
<th>Geoid Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geoid09</td>
<td>Used in the example to obtain an estimated Orthometric Height</td>
</tr>
<tr>
<td>Geoid99</td>
<td>Current Survey Control System</td>
</tr>
</tbody>
</table>

**Example:**

1. Calculate $h$ using Geoid09 and Geoid99.
2. Compare the results with measured values.

**Computed EHs:**
- Geoid09: $h = H + N$
- Geoid99: $h = H + N$

**Results:**
- New EHs are closer to measured values.
- Better geoid models improve accuracy.

---

Geoid: Recovery

- The NGS gravimetric geoid model USGG2012 used with ITRF, IGS or WGS84; and the GR80 Ellipsoid provides the best estimate of the geoid.
- GEOID12A, a hybrid geoid model, estimates NAVD88 heights when referenced to the GR80 Ellipsoid centered in NAD83(2011).
- The important advantage of geoid models is not so much in estimating the geoid or an NAVD88 height, but in applying the difference in the differences. The precision of the model is not in the absolute geoid height, but in the difference in heights at two locations. Combining the difference in the geoid heights with the difference in the measured ellipsoid heights between two points will approach leveling accuracies.

---

Example: Determine Orthometric Heights with a geoid model comparable to leveling

Use GNSS to measured between two points and applying $H = h - N$ to check the leveling. This method should agree within centimeters.

**Example:**

1. Measure points A and B using GNSS.
2. Use GNSS to calculate $h$ and $N$ for each point.
3. Apply $H = h - N$ to check leveling accuracy.

**Results:**
- Agreement within centimeters.

---

The Future Geoid

- The present NGS GRAV-D Program combines satellite and airborne gravity measurements with the intention of defining a geoid model with a relative precision of one centimeter. In the next ten years a new National Vertical Datum will replace NAVD88 facilitating the measurement of orthometric heights within 2 centimeters anywhere anytime (the combined error of the model + measured ellipsoid height).
Tidal Datums

Tides are the result of gravitational and meteorological forces interacting with the physical configuration of the shoreline and sea bed. Tidal heights will vary along the shoreline.

Tidal Datums are defined for:
- Mean Higher High Water (MHHW)
- Mean High Water (MHW)
- Mean Sea Level (MSL)
- Mean Tide Level (MTL)
- Mean Low Water (MLW)
- Mean Lower Low Water (MLLW)

The National Ocean Survey (NOS) observes the tides at 26 primary and numerous secondary and tertiary tide stations around North America and offshore.

Precise determination of the elevation of tidal datums at a specific location requires observations of the tide for 18.61 years (taken as 19 years to round out seasonal events).

The water heights at these tide stations are published based on a 19 year epoch. The present National Tidal Datum Epoch is 1983-2001. (Previous 1960-1979).

Tidal Datums

- Tide Stations are referenced by permanent monuments in their vicinity called Tidal Benchmarks. Benchmark descriptions and heights are available at the NOS.

- At each Tide Station, Mean Lower Low Water for the particular 19 year epoch is taken as zero and is referenced to Tidal Benchmarks and available at the NOS.

- Tidal benchmarks were usually connected to the National Geodetic Vertical Datum of 1929 (NGVD 1929) in years past and presently to the North American Vertical Datum of 1988 (NAVD88).

Tidal Datum Recovery

- Tidal Datums can be recovered in the vicinity of a Tide Station by a direct measurement from the Tidal Benchmarks.

- Tidal Datums can be recovered indirectly by equating the desired datum i.e. MHW to NAVD88 and recovering NAVD88 Benchmarks.

- Relative to a Primary Tide Station, a local Tidal Datum can be determined by observing for:
  - 13 months to yield an elevation within 0.1 feet
  - 30 days to yield an elevation within 0.2 feet
To access NOS Tide Station Data: Go to http://tidesandcurrents.noaa.gov/, click on the interactive map (below), choose the region, set the data type to “Benchmark Sheets”, zoom in on the area of interest, and click on a station to see details.

Click on “Benchmark Sheets” to see the Station Information, Tidal Benchmarks, and the Tidal Datums (following)
Tide Station Information

- **Tide Station Zero Reference**: -0.103m on NAVD88
- **Benchmark ID and height above MLLW**: NAVD88 = 1.771m

**Tidal BM NGS Data Sheet and Graph**

- **Graph obtained at NGS Website**: http://www.ngs.noaa.gov/newsys-cgi-bin/ngs_opsd.prl
- **National Geodetic Survey Data Sheet**: National Geodetic Survey, Retrieval Date = FEBRUARY 24, 2012

**HT0702**

- **This is a Tidal Bench Mark**
- **Designation**: 941 4290 TIDAL 180
- **PID**: HT0702
- **State/County**: CA/SAN FRANCISCO
- **USGS Quad**: SAN FRANCISCO NORTH (1995)
- **NAD 83(1986)**
  - Latitude: 37 48 19.28 (N)
  - Longitude: 122 28 00.38 (W)
- **NAVD 88**: 3.996 (meters) 13.11 (feet) ADJUSTED
- **GEOID HEIGHT**: -32.55 (meters) GEOID09
- **DYNAMIC HT**: 3.994 (meters) 13.10 (feet) COMP
- **MODELED GRAV**: 979,982.4 (mgal)

The horizontal coordinates were established by differentially corrected hand held GPS obs and have an estimated accuracy of +/- 3 meters.
The orthometric height was determined by differential leveling and adjusted in June 1991.
This Tidal Bench Mark is designated as VM 967 by the CENTER FOR OPERATIONAL OCEANOGRAPHIC PRODUCTS AND SERVICES.

**Remote Locations**

- In locations remote to Tide Stations where benchmarks are available, and assuming the Tidal Datum surface is linear, the Tidal Datums could be equated to NAVD88 Heights and interpolated between the nearest Tide Stations.

- Note that the difference in the height of MLLW relative to NAVD88 between Eureka and Crescent City is 0.03' in 75 miles. The gradient (if assumed to be linear) between Santa Barbara and San Francisco is 0.002'/mile.

**Tidal Datum Recovery**

- The height of a Tidal Datum like Mean High Water can be determined by observing a predicted high tide that corresponds to the level of Mean High Water at a known tide station and simultaneously at a local site.

Tidal Datum Recovery

- Build your own portable tide station shown here at Morro Bay by Robert Reese, PLS.

MHW Datum: a Riparian Boundary

- The Federal Court in 1935 in *Borax Consolidated, Ltd. v. Los Angeles* (1935) 296 U.S. 10, defined the Ordinary High Water Mark to be the Mean High Water Line based on the average of all high waters (higher high and lower high) occurring over a tidal epoch of 18.61 years.

- The Federal Rule has been followed in California for the practical reason that tidal data are published by the National Ocean Survey for all high tides over a 19-year period and information is not readily available to determine the height of Neap High Tide. The California State Lands Commission has followed the Federal Rule since 1938.

MHW Datum: a Riparian Boundaries

- In CA the tidal boundary between the state and an upland (riparian) owner is the ordinary high water mark in its last natural condition. (Civil Code Section 670 and 830)

- California courts in 1861 defined the ordinary high-water mark as the limit reached by the Neap Tides.

- Neap Tides are the more moderate tides occurring during the first and third stages of the Moon.

National Geodetic Vertical Datum 1929 (NGVD29)

- NGVD29 was the national vertical datum until superseded by NAVD88 in 1991.

The origin of zero was derived from an adjustment of the national leveling network constrained to Mean Sea Level at 26 tide stations along the east and west coasts of the US and Canada.
National Geodetic Vertical Datum 1929 (NGVD29)

- NGVD29 is an early attempt to model the geoid by constraining a continent of precise leveling measurements to mean sea level assuming it represented the geoid.

- Subsequently, over 60 years of “Supplemental Adjustments” were published conforming to the original adjustment and re-distributing inconsistencies.

North American Vertical Datum 1988 (NAVD88)

- NAVD88 superseded NGVD29 when it was published in 1991. The datum zero was intended to approximate a geoid surface. However, it is now known that a continental tilt of about a meter exists in NAVD88 (the elusive geoid).

- NAVD88 heights are “Helmert Orthometric Heights” which take into account the effects of gravity in the reduction of observations.

- A new national First Order leveling network called the “A” Net was observed between about 1978 and 1991.

- Heights are based on a minimally constrained least squares adjustment of the “A” Net fixing a single benchmark on the Saint Lawrence Seaway in the northeastern US.

- Benchmarks in the “A” Net are so indicated by the term “ADJUSTED” shown on NGS Datasheets.

- Only about 25% of the 50,000 benchmarks in California were included in the “A” Net. The remaining were re-adjusted as follows.

- Some benchmarks heights were re-adjusted loops using old measurements constrained to the new “A” Net and are indicated by the term “POSTED” shown on DS’s (amount of error distribution is listed).

- Other benchmarks not included in the A-Net had their NGVD29 elevations shifted to NAVD88 by applying the NGS VertCon program and are indicated by “VERTCON” shown on DS’s.

- NAVD88 and NGVD29 are unrelated datums. They differ in their origins, definitions of height, measurements, adjustments, and constraints.

- There is no consistent relationship between the two systems. However, in a local area, it may be possible to determine a reliable shift given sufficient benchmarks in both datums.

- In California, NAVD88 heights will be a larger value than NGVD29 by 70-100 cm or 2-3 feet (telltale sign)
Example: Vertical Datum Relationships

- Shown below are NGVD29, NAVD88 and NAD83 Ellipsoid Heights at Port Hueneme, California at HPGN-D Station “941 1065 TIDAL 6 RESET

<table>
<thead>
<tr>
<th>Ellipsoid Height (h) = -104.60' M</th>
<th>Geoid Separation (N) = 118.70'</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.12' M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HPGN > Elv: NGVD29 = 11.96', NAVD88 = 14.12', NAD83 = -104.60'  

Recovery: NGVD29 & NAVD88

- NGVD29 & NAVD88 datums are referenced by benchmarks in the NSRS and described on NGS Datasheets.
  - Caveat: A mark’s position may change due to the dynamic nature of the earth’s crust; the coordinates of a mark can only be certain at the date of the field survey.

- Datasheets list:
  - NGVD29 benchmarks under “Superseded Survey Control”
  - NAVD88 benchmarks at the top (“ADJUSTED” is best)

Note: Recovering one benchmark is not sufficient to recover the datum. At least two must be leveled and found in agreement.

Recovery: NGVD29 & NAVD88

Access Datasheets at the NGS website: http://www.ngs.noaa.gov/cgi-bin/datasheet.prl
Click on “DATASHEETS”, “Radial Search”, and enter coordinates for the search area. Set the “Data Type” to “Any Vertical Control”.

- For NGVD29, look under “Vertical Source” for benchmarks with “29/…”
- For NAVD88, look under “Vertical Source” for benchmarks with “88/……”.

Recovery: NGVD29 & NAVD88

The NGS utility DSWIN will read a text file containing Datasheets (downloaded from the NGS) and extract a list of stations by data types. For example, extract all benchmarks with NGVD29 heights by selecting “SUPER_NGVD29_DATA”.

Instructions: Download the utility at http://www.ngs.noaa.gov/PC_PROD/DSWIN/
Run the program, specify a file containing Datasheets, choose FILE, SAVE AS, and specify a name for the new file, choose DSSELECT for Output Format, and select the data types.
Recovery: VertCon 88 $\leftrightarrow$ 29 Model

- VertCon is a model based on benchmarks with heights common to both NGVD29 and NAVD88. VertCon computes the difference between the two datums given the latitude and longitude. (NGS accuracy claimed is 2 cm).

- Caveat: The accuracy of recovering an NAVD88 height is dependent on the local availability and density of benchmarks common to both datums and the stability of the monument keeping in mind the NGVD29 field surveys occurred over many years prior to about 1978.

- Suggestion for validating VertCon: Look for the nearest benchmarks with both datums and compare their differences with VertCon.

NAVD88 - Recovery

- Ellipsoid heights can be combined with a hybrid geoid model to obtain estimated NAVD88 Heights better than 10 cm.
  - (NAD83(2007) EH + Geoid09  ~ NAVD88)
  - (NAD83(2011) EH + Geoid12a  ~ NAVD88)

Graphic Apps for Researching Control

- Earth Survey has a collection of geodetic tools that run in Google Earth. NGSCS is a graphical front end for viewing NGS stations and Datasheets. QUADS and PLSGE provide access to data and images from the USGS and BLM. Seven other tools (DeflecGE, GeoidGE, MagDec, NADGE, SPCGE, VERGE, and XYZGE) are graphical front ends for programs in the NGS Geodetic Tool Kit. http://www.metzgerwillard.us/EarthSurvey.html

- Trial Version of the new NGS Map Tool available: http://beta.ngs.noaa.gov/googletest/NGSMap/NGSMap.shtml


Horizontal Datums

- 2D: Horizontal
  - Ellipsoids
  - NAD27 - North American Datum 1927
  - NAD83 - North American Datum 1983
CONCEPTS: Ellipse and Ellipsoid
Mathematical Model of the Earth

\[ a = \text{Semi major axis} \]
\[ b = \text{Semi minor axis} \]
\[ f = \frac{a-b}{a} = \text{Flattening} \]

<table>
<thead>
<tr>
<th>Ellipsoid</th>
<th>(a) (m)</th>
<th>(1/f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRY 1830</td>
<td>6377563.396</td>
<td>299.3249646</td>
</tr>
<tr>
<td>BESSEL 1841</td>
<td>6377397.155</td>
<td>299.1528128</td>
</tr>
<tr>
<td>CLARKE 1858</td>
<td>6378293.645</td>
<td>294.26068</td>
</tr>
<tr>
<td>CLARKE 1880</td>
<td>6378249.145</td>
<td>294.9786982</td>
</tr>
<tr>
<td>EVEREST 1830</td>
<td>6377276.345</td>
<td>300.8017</td>
</tr>
<tr>
<td>GRS 80</td>
<td>6378137</td>
<td>298.2572221</td>
</tr>
<tr>
<td>HOUGH 1956</td>
<td>6378270</td>
<td>297.0</td>
</tr>
<tr>
<td>INTERNATIONAL</td>
<td>6378388</td>
<td>297.0</td>
</tr>
<tr>
<td>KRASSOVSKY 1938</td>
<td>6378245</td>
<td>298.3</td>
</tr>
<tr>
<td>PZ90</td>
<td>6378136</td>
<td>298.2578390</td>
</tr>
<tr>
<td>WGS 66</td>
<td>6378145</td>
<td>298.25</td>
</tr>
<tr>
<td>WGS 72</td>
<td>6378135</td>
<td>298.26</td>
</tr>
<tr>
<td>WGS 84</td>
<td>6378137</td>
<td>298.2572236</td>
</tr>
</tbody>
</table>

NAD27, NAD83 Ellipsoids and the Geoid

NAD83 (GRS80)
Fits Global Geoid

NAD27 - CLARKE 1866
Fits North America

Earth Mass Center
Approximately 236 meters

GEOID

North American Datum 1927 (NAD27)

- Oldest Continental System established 1920's
- The origin is the best known latitude & longitude at station "Meads Ranch" in Kansas, orientated to station "Waldo".
- The Ellipsoid is Clark's Ellipsoid Of 1866, orientated to fit North America.
- The NAD27 ellipsoid surface is assumed to be at sea level therefore, NGVD29 elevations were used to compute the State Plane Coordinate (SPC) height reduction factor to develop the combined grid factor for SPC surveys.

NAD27

National adjustment of baselines and triangulation measurements established 25,000 stations, with an average precision of 1:100,000.
North American Datum 1983 (NAD83)

- Satellite geodesy and the introduction of laser distance measurement systems in the 60’s and 70’s exposed intolerable inconsistencies in the NAD27 Network.
- This spurred the NGS to develop the North America Datum of 1983.
- The NGS adopted the GRS80 Ellipsoid for NAD83 Datum because it best fit the global geoid.

VLBI Network – Reference Frame for NAD83

There existed at the time, a 3D global network called the Very Long Baseline Interferometry (VLBI) network which provided the primary reference frame for the realization of NAD83.

NAD83(86)

- High precision trans-continental EDM traverses were measured to strengthened the NAD27 triangulation networks and connect to the VLBI Network.
- NAD27 measurements were combined with new measurements in an adjustment to strengthen the network and remove inconsistencies.
- The NAD83 Adjustment established new positions on 250,000 stations with an average precision 1:300,000.
- NAD83 was introduced in 1986 and is commonly referred to by it datum tag NAD83(86).
- The adjustment epoch date is 1984.00.

NAD83(86) Verses NAD27

- NAD83 and NAD27 use different ellipsoids, different constraints, and are realized by adjustments of different sets of measurements, resulting in the realization of two datums on the same monuments.
- There is no consistent relationship between NAD83 and NAD27.
- The shift from NAD27 to NAD83 is about 20-30 feet in latitude and 300 feet in longitude in CA.
- The scale and orientations are similar.
Recovery: NAD27 & NAD83(86)

- NAD27 & NAD83 are referenced by passive monuments in the NSRS and described on NGS Datasheets.
- Datasheets list NAD27 and NAD83(86) stations under "Superseded Survey Control".
- Stations that existed prior to about 1990 will have NAD83(86) positions because they preceded GPS and do not have ellipsoid heights.
- Caveat: A mark's position may change due to the dynamic nature of the earth's crust; the coordinates of a mark can only be certain at the date of the field survey.

Access Datasheets at the NGS website http://www.ngs.noaa.gov/cgi-bin/datasheet.pl
Click 'DATASHEETS', 'Radial Search', and enter coordinates for the search area, set the “Data Type” to "Any Horizontal Control".

For NAD83, choose First Order or less stations (all horizontal stations that existed prior to about 1990 will have an NAD83(86) position).

For NAD27, choose First Order or less stations, most will have NAD27 values. (use DSWIN to sort superceded values)

Definition

- Transformation: A mathematical process for moving points from one coordinate system to another by some combination of translations, rotations and scale.

Conformal (Helmert) transformations are most appropriate for common survey applications. There is the 2D (4 parameter) and 3D (7 parameter) transformation.

Photogrammetrist often use an affine transformation because it solves for scale along individual axis.

Trimble uses the term calibration, some use localization, but they meant transformation.

2D Transformation - Best Method: Include a minimum of two stations in the survey with NAD27 SPC or NAD83(86) SPC values and compute a 2D conformal transformation.

If three or more stations are available then the residuals will be indicators of the success of recovery.

If only two stations are available then check the scale and rotation. If working in NAD83 SPC or transforming between NAD83 SPC and NAD27 SPC, expect a scale of one and a rotation of seconds.
Recovery: NAD27 & NAD83(86)

- The NGS program NADCON will convert between NAD83 and NAD27 with an accuracy of about ½'. (GIS)
- The NGS program "NADCON HPGN" will convert NAD83 HPGN positions to NAD83(86). (NGS stated accuracy is 5 cm).
- Corpscon v6 Software (find on Internet) includes VertCon, NadCon, NadCon HPGN and Geoid Models to perform conversions between datums and will convert graticule coordinates to grid and vice versa.

Geometric Datums

- 3D: Geometric
  - North American Datum 1983 (NAD83)
  - World Geodetic System 1984 (WGS84)

North American Datum of 1983 (in 3D)

- NAD83(86) was short lived because the advent of GPS made its inconsistencies glaring apparent. Any surveyor with GPS was capable of making high precision measurements (not just the NGS).
- NAD83 already had the elements of a 3D system because it was based on the GRS80 Ellipsoid and was referenced by the 3D VLBI network.
- The center of the GRS80 Ellipsoid is the origin of a three dimensional XYZ cartesian coordinate system. The origin was intended to be at the Earth’s center of mass.
- Positions measured with GPS are in XYZ Cartesian Coordinates. (XYZ are converted to latitude, longitude and ellipsoid heights and then to a grid).

Cartesian Coordinate System: Defines 3D Space

Origin (A) is 0,0,0 at the center of the GRS80 Ellipsoid intended to be at the center of mass; the X-Y Plane coincides with the equator with the +X axis pointing towards Greenwich (B); and, the Z Axis coincides with Earth's mean axis of rotation with +Z points pointing towards the N. Pole (C).
NAD83 in 3D – The Beginning

- In the late 1980’s, the NGS began a program based solely on GPS to establish independent high accuracy 3D networks to improve the NSRS.

- These 3D network realizations of NAD83 were called High Accuracy Reference Networks (HARN).

- HARN’s were surveyed and adjusted on a state by state basis between 1990 and 1997.

High Accuracy Reference Networks

In California, the HARN is referred to as the High Precision Geodetic Networks (HPGN).

The CA HPGN adjustment was completed in 1992 and is referred to by a datum tag of NAD83(92).

North American Datum 1983
NAD83(92)

- The HPGN network was constrained to the original VLBI Network creating 3D coord’s
  - The VLBI was an AA Order network (1:100,000,000)
  - The HPGN was a B Order network (1:1,000,000)

- The HPGN network introduced two new concepts to surveyors:
  - Epoch and Datum Tags
  - Ellipsoid Heights (a third dimension)

NAD83(92) Ellipsoid Heights

- Origin for EH’s is zero at the surface of the GRS80 ellipsoid

- EH’s are normal to the ellipsoid surface, unlike orthometric heights which are normal to the geoid

- The HPGN monuments provided access to ellipsoid heights for the first time because they not available with NAD83(86).
**NAD83(92) – Ellipsoid vs Geoid**

- Ellipsoid heights are interesting but surveyors prefer a gravity based height system where water flows downhill.
- The concept of a geoid height was introduced to the surveying community by the NGS with Geoid90.
- Geoid90 and Geoid93 were the first gravimetric geoid models.
- Surveyors were now able to use their GPS measured ellipsoid heights to estimate elevations. Better geoid models followed as discussed previously.

**NAD83 Epochs**

- NAD83 is fixed to the North American Plate (easterly of the San Andreas Fault). A large part of California in moving with respect to the North American Plate, and because of GPS, we can measure and report this.
- It necessary in California to state the epoch of surveys because the positions change as much as 5 centimeters per year relative to the North American Plate.
- Surveys that are referenced to monuments with NGS sanctioned NAD83 positions must state the Epoch being used. This is important since other surveyors before or after may use the same monument with a different epoch position.

Furthermore, our surveys must be referenced to NGS or CSRC sanctioned epochs for uniformity and to give validity to the SPC’s as required by the PRC.

Previous NGS and CSRC sanctioned epochs are not invalid because they are superseded. The position is still valid for the particular epoch on a monument. Tools provided by the NGS (HTDP) and CSRC (SECTOR) can be used to change from one epoch to another.

Some have used the CSRC SECTOR utility to obtain "day-of-observation positions" and argue that they satisfy the requirement for a sanctioned epoch; however, it that is not the intent of the PRC. The intent is to base surveys on a common sanctioned published epoch.

**NAD83 (19xx.xx) Epochs**

- An epoch date is assign to the coordinates (realization) based on the average date of the field observations.
- The original CA HPGN GPS survey is referred to as NAD83(1991.35) which is its Epoch Tag used in calculations relating different epochs.
- This nomenclature is required by the CA Public Resources Code Section 8815.1 and 8815.2. “CCS83(1991.35)” is the correct way to refer to State plane coordinates.
- NAD83(1991.35) is commonly referred to as NAD83(92) which is its Datum Tag. The NGS DS’s will show both the datum tag and the epoch tag.
HPGN - NAD83(1991.35)

- The HPGN survey established about 240 "B" Order stations in California. Subsequently, the HPGN-D densification surveys established stations about every 10-20 kilometers along state highways constrained to the "B" Order Network.

- An NAD83(86) First Order triangulation stations was included in the HPGN survey in every 1 degree quad. These stations were later held fixed in a re-adjustment of conventional triangulation network measurements to upgrade their NAD83(86) positions to NAD83(1991.35) positions.

- The upgraded triangulation stations have the NAD83(92) datum tag, but do not have ellipsoid heights. They are not equivalent in precision to the HPGN. (better absolute accuracy, not relative)

NAD83 Adjustments Epochs by the NGS

Earthquakes and special projects required re-surveys and re-adjustments of regional areas in CA leading to multiple Epochs.

- 1984.00 NAD83(86) initial national adjustment creating NAD83
- 1991.35 NAD83(92) HPGN B-Order Network in CA, first time GPS and ellipsoid heights; followed by densification surveys
- 1992.88 Regional CA re-adjustment for Landers' EQ
- 1995.00 Regional CA re-adjustment for Northridge EQ
- 1995.50, 1996.0, 1997.30 numerous adjustments occurring in CA
- 1998.50 A-Order Federal Base Network Stations

2002.00 NAD83(CORS96) The national CORS solution shown on DS's up until July 2012

2007.00 NAD83(2007) National re-adjustment to harmonize state HARN’s. 700 CORS were fixed on the NAD83(CORS96) 2002.00 Epoch. In California the CORS were fixed on the 2007.00 Epoch. The NAD83(86) stations were not included.

2010.00 NAD83(2011) National re-adjustment of 1800+ CORS released in September 2011 followed in July 2012 by a re-adjustment of the passive HARN networks. Finally, we are all on the same epoch, but what about the the NAD83(86)/NAD83(92) passive monuments 2022? Proposed new geometric datum coinciding with ITRF/IGS?

CGPS: a California CORS Network

- SCIGN, PBO, and others have established permanent GPS reference stations over the last two decades. The California Spatial Reference Center (CSRC) http://csrc.ucsd.edu/ working with SOPAC at the University of San Diego has leveraged these systems to develop a CORS for California. These are referred to as the Continuous GPS (CGPS) stations and constitute the primary component of the California Spatial Reference Network (CSRN).
**California Spatial Reference Network**
830 CGPS Stations

---

**CSRC NAD83 Adjustments of the CGPS**

- The NGS and the CSRC have partnered for the last decade to provide geodetic services in CA. The coordinates published by the CSRC, can be found at http://csrc.ucsd.edu/ and are sanctioned by the Public Resources Code (PRC). (NGS?)


- The CSRC CGPS 2007.00 Epoch is consistent with the National NAD83(2007) Adjustment which is based on the CORS(96) 2002.00 Epoch. The CSRC 2009.00 and 2011.00 Epochs are based on 2007 Adjustment. The present CSRC adjustment of the CGPS is referred to as NAD83(2007) 2011.00 Epoch.

- Be Aware: The CSRC NAD83(2007) 2011.00 Epoch is not the same as the NGS NAD83(2011) Adjustment, which is on the 2010.00 Epoch. NAD83(2007) [CORS(96) 2002.00] and NAD83(2011) [CORS 2010.00] are two very different realizations of NAD83.

---

**NGS NAD83(2011) 2010.00 vs. CSRC NAD83(2007) 2010.00 ADJUSTMENTS**

<table>
<thead>
<tr>
<th>NGS</th>
<th>CSRC (SECTOR)</th>
<th>Diff(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAD83(2011) EPOCH 2010.00</td>
<td>NAD83 (2007) EPOCH 2010.00</td>
<td></td>
</tr>
<tr>
<td>At CORS and CGPS Station P162</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latitude</td>
<td>40-41.27.92827</td>
<td>40-41.27.92828</td>
</tr>
<tr>
<td>Longitude</td>
<td>124-14.13.27512</td>
<td>124-14.13.27544</td>
</tr>
<tr>
<td>Ellips. Ht</td>
<td>-6.043m</td>
<td>-6.045m</td>
</tr>
</tbody>
</table>

| At CORS and CGPS Station LORS |
| Latitude | 34 07 59.96493 | 34 07 59.96500 | N 0.002 |
| Longitude| 117 45 14.60442 | 117 45 14.60445 | E -0.001 |
| Ellips. Ht| 449.603m       | 449.597m       | Up -0.006 |

---

**NAD83(xxxx.xx) 3D - Recovery**

- Referenced by passive monuments (the ones with ellipsoid hts) described on NGS Data Sheets (DS).

- DS’s list the latest NAD83(xxxx.xx) epochpositions under “Current Control”.
  - See “Superseded Control” for prior epochs.

- Access DS’s at the NGS website: http://www.ngs.noaa.gov/cgi-bin/datasheet.prl
  Click “DATASHEETS”, “Radial Search”, enter the coordinates for the search area, set the “Data Type” to “GPS Sites Only”. All stations with ellipsoid heights should be retrieved.
NAD83 – Recovery via CGPS

- NAD83 is referenced by the CGPS at [http://csrc.ucsd.edu/](http://csrc.ucsd.edu/)

Go to the link, identify the nearest stations, and download the coordinate files and static observation files (Rinex Files) that correspond to your static on-site observations. Process the static data and run a network adjustment to determine valid coordinates on your survey. (see CalSurveyor 2011 three part article)

NAD83 – Recovery via CRTN

NAD83 is referenced by the California Real Time Network (CRTN) established and maintained by the CSRC. [http://sopac.ucsd.edu/projects/realtime/](http://sopac.ucsd.edu/projects/realtime/)

CRTN utilizes a subset of CGPS stations upgraded to real-time data telemetry to provide a single baseline solution.

CRTN therefore, provides real time positioning via an internet connection based on measurements (vectors) from positions of the CGPS reference stations operating as CRTN stations.
Advantages of Using CGPS/CRTN

- Active CGPS/CRTN stations have an advantage over passive monuments for the following reasons:
  - Surveyors do not have to physically occupy monuments to reference their surveys to NAD83 coordinates
  - Highest accuracy reference monuments available
  - The CGPS are monitored daily, and if they move or are disturbed, it is detected within 24 hours. Whereas, the position of a passive station is only known at the time it was last measured. For the HPGN this dates back to 1991.
  - Most important! Surveyor’s have access, unlike private RTN’s, to sanctioned NAD83 coordinates in Real Time with CRTN than can be published on a RS.

HTDP

Online HTDP (Horizontal Time-Dependent Positioning) Program will model the secular and episodic motions relative to the North American Plate (accuracy?)

http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml
World Geodetic System 1984 (WGS84)

- WGS 84 is the 3D reference frame used for the Global Positioning System (GPS) maintained by the Air Force for the DOD.
- WGS 84 (G1674) is the latest realization of WGS84 in February 2012 by the National Geospatial Intelligence Agency (NGA) (formerly the National Imagery and Mapping Agency).
- G1674 refers to the GPS week when computed GPS Broadcast Orbits began using this frame. The original WGS84 frame was updated from a doppler satellite based frame to GPS based in 1994.

WGS84

- The WGS84(G1674) reference frame conforms to ITRF08 Epoch 2005.00. For more information see:
  - “Recent Updates to the WGS84 Reference Frame” by R. Wong, C. Rollins, National Geospatial Intelligence Agency presented at the ION GNSS 2012, Session A3: Geodesy, Surveying & RTK for Civil Applications

WGS84 GPS Positions

- It is a common misconception that the resultant position of a GPS survey is referenced to WGS84.
- This would be the case if we were using GPS in an absolute mode (no reference/base station).
- In the differential or relative positioning GPS mode, the geospatial coordinates will be in the datum the reference receiver is assigned.
  - (NAD83 in -> NAD83 out) (WGS84 in -> WGS84 out)
WGS84 vs. NAD83 (What’s the Difference?)

WGS84=ITRF08=IGS08 Geocentric Datums
NAD83 is not geocentric and is about 2 meters from the center of mass.

NGS Coordinates at CORS Sta. LORS PID=DM7524

EPOCH                     2010.00                   2005.00
LATITUDE           34 07 59.96493      34 07 59.97575             +1.09'
LONGITUDE 117 45 14.60442    117 45 14.64802               -3.66'
ELLIP. HT. 449.603m               448.890m                -2.33'
3D Difference = 1.37m = 4.48'
Scale differs 1ppb+/-
3 Rotations <0.01"+/-

Satellite Ephemeris

Orbit Errors & WGS84

Satellite Ephemeris

WGS84 Recovery

- Measurements with GPS receivers result in WGS84 vectors between points, but the positions are in the datum of the reference receiver.
- Generally, monuments referencing WGS84 do not exist outside of military bases.
- ITRF/IGS positions are available for the CGPS, CRTN and CORS stations.
- The NGS Horizontal Time Dependant Positioning (HTDP) program will transform NAD83 positions to WGS84/ITRF.
HTDP

HTDP (Horizontal Time-Dependent Positioning) Program performs transformations between reference frames: NAD83, WGS84 and ITRF

Geometric + Time Datums

- International Terrestrial Reference System (ITRS) is a dynamic coordinate system including time.
- High precision positions and velocities take into account the natural movement of the earth’s surface to determine real time coordinates.
- NGS has adopted the International Terrestrial Reference Frame ITRF08 2005.00 Epoch as a Reference Frame and based the CORS NAD83(2011) adjustment on the IGS08 2005.00 Epoch
- For more information about ITRF coordinates see the ITRF readme file at the NGS web site.

Final Thought

- “….. it is far more important to have a somewhat faulty measurement of the spot where the line truly exists than to have an extremely accurate measurement of the place where the line does not exist at all”

A.C Mulford, Boundaries and Landmarks, 1912

THE END

- Questions & Comments:
  - Questionnaire: Three Questions for Participants
    - 1- Name one or more significant things that you learned here today:
    - 2- Name one or more significant things that you are still unsure about after today:
    - 3- Name one or more significant things that you would like to know more about:
Grid Projections (Grid Coordinate Systems)

- SPC: State Plane Coordinate System (Lambert or Mercator)
- UTM: Universal Transverse Mercator

California State Plane Coordinate Zones & Scale Factors

- SPC defined in the Public Resources Code (PUC) Section 8813 etc. Zones include specific counties as shown.
- Grid Scale Factor <1:10,000 by design
- Lambert (conical) Projection in CA
- NAD83 absorbed Zone 7 into Zone 5
- PRC requires SPC be based on First Order control determined by GPS
- NAD83 & NAD27 have similar Factors and Convergence for Zones 1-6

Universal Transverse Mercator

- Based on the Mercator (cylindrical) Projection
- Zones are 6° wide N & S of Equator
GROUND LEVEL COORDINATES
“IF YOU DO”
TRUNCATE COORDINATE VALUES
SUCH AS:
N = 1,750,260.07 ft becomes 50,260.07
E = 6,099,440.89 ft becomes 99,440.89

Antenna Models
NGS's CORS group began using Absolute Antenna calibrations upon the release of the new CORS coordinates in IGS08 Epoch 2005.00 and NAD83(2011,MA11,PA11) Epoch 2010.00.

NGS Antenna Calibration page at http://www.ngs.noaa.gov/ANTCAL/
states Absolute Antenna Calibration values are now the default values on this page. These Absolute values should be used when processing data with CORS coordinates. These calibrations are different from previous Relative Antenna calibrations.

What does this mean to the users?

TERMINOLOGY
- Active Monuments: Reference points monitored in near real time and usually accessible via the internet, i.e. CORS, CGPS, RTN
- Passive Monuments: In the ground points referencing the datum
- National Spatial Reference System (NSRS): A consistent coordinate system that specifies Latitude, Longitude, Height, Scale, Gravity & Orientation; how these values change with time; and a high accuracy geographic reference framework throughout the United States. Formerly called the National Geodetic Reference System (NGRS).
- Transformation: A mathematical process for moving one coordinate system to another by some combination of translations, rotations and scale. A conformal (Helmert) 2D and 3D are most common. Photogrammetrist use an affine transformation (aka calibration by Trimble)
Statement regarding control used for the NAD 83(NSRS2007)

- Control for the NAD 83(NSRS2007) adjustment was provided by the CORS. For all states except AZ, CA, OR, WA, NV and AK, the values used were the NAD83 CORS(96) Epoch 2002.0 values currently published by NGS.
- In California, the NAD 83 values used for the California CORS and the National CORS were provided by the CSRC in epoch 2007. These values are currently published by CSRC and available from their website.
- For AZ, OR, WA, NV and AK, HTDP was used to convert the published NAD83 positions of the CORS(96) Epoch 2002.00 to Epoch 2007.00.
- For all stations on the stable North American plate, no epoch date is shown – as has been the practice. For the other states, an epoch date of 2007.0 is shown. In those states, except CA, HTDP can be used with the currently published CORS to determine the proper value to use. In CA, the values as currently published on the CSRS website can be used with HTDP (if necessary).

Datum Topics

- Geoid and Geoid Models
- Ellipsoid and Cartesian Coordinate System (XYZ)
- Reference Systems
- Grid Projections
- NGS Data Sheets
- Antenna Models and SV Orbits
- Reports and Adjustments (time?)

Datum ? What Datum ?

- Where are you?
- Where do you want to be....