History of the Development of Geodetic Datums in the United States

Vermont Society of Land Surveyors
Colchester
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NINTH CONGRESS OF THE UNITED STATES.

At the Second Session.

Begun and held at the city of Washington, in the territory of Columbia, on Monday the first of December, one thousand eight hundred and six.

AN ACT To provide for surveying the coasts of the United States.

Be it enacted by the Senate and House of Representatives of the United States of America, in Congress assembled, that the President of the United States shall be, and he is hereby authorized and required, to cause a survey to be taken of the coasts of the United States, in which a chart be drawn of the islands and shoals, with the sounds, bays, and inlets of the shores of the United States; and also the various courses and distances between the principal points on land and sea, together with such other matters as he may deem proper for completing an accurate chart of every part of the coasts within the United States.

Sec. 2. And be it further enacted, that it shall be lawful for the President of the United States, to cause such communications and observations to be made, as will enable him to have a true and correct chart of the said coasts, and the several routes and points beyond the distance referred to the said coast, from his opinion may be materially amended or the commercial interest of the United States.

Sec. 3. And be it further enacted, that the President of the United States shall be, and he is hereby authorized and required, to cause all the papers, writings, and accounts hereinbefore mentioned, in his opinion, to be kept, and also such other papers as he may deem proper, to be impounded, and to give such instructions for keeping, using, and destroying the same, as he shall deem proper, according to the tenure of the said.

Sec. 4. And be it further enacted, that for carrying this act into effect there shall be, and hereby is appropriated, an sum not exceeding fifty thousand dollars to be paid out of any money in the Treasury, not otherwise appropriated.

Speaker of the House of Representatives

[Signature]

Vice President of the United States and President of the Senate

[Signature]

January 22, 1807

[Signature]

Printer, in the House of Representatives

[Signature]

1807

PRETENTHOMS JEFFERSON SIGNS LEGISLATION

ESTABLISHING THE SURVEY OF THE COAST
FERDINAND HASSLER (1770-1843)

Hassler's First Field Work, 1816-1817
24-Inch Troughton & Simms Theodolite in Hassler’s Camp
Weight approx. 1000lbs required 10 men to move
Everest’s Theodolite Similar to Hassler’s
What’s In a Name?

1807 - Survey of the Coast
1836 - Coast Survey
1878 - US Coast and Geodetic Survey
1970 - National Ocean Service
   National Geodetic Survey
TRANSCONTINENTAL ARC OF TRIANGULATION
1872 - 1898
August 28 to September 22, 1885

Coast and Geodetic Survey—Transcontinental Triangulation

No. 41

HIGH SUMMIT STATION, TUSHAR MOUNTAIN, UTAH, SHOWING RING WALL AND DOUBLE SHELTER TENT AGAINST STORMS AND RADIATION OF HEAT.

Altitude, 3,702 meters or 12,146 feet.
Figure 1
Geodetic Control For 1901 Adjustment - The North American Datum
Triangulation Schemes
Tower Construction

90 ft
New Type of Wooden Tower
designed by J.S. Bilby
1905

Material
Lumber -- 5,200 ft
Nails -- 300 lbs

LABOR:
Skilled workmen -- 2
Common labor -- 3
Foreman J.S. Bilby -- 1
Total -- 6

Number of days required to build complete = (3) Three.

116 Foot
Bilby Portable Steel Tower

Five men dug the holes, erected the tower and set the station marks in six hours flat.
USC&GS/NGS Marker Types

**Know These Markers**
- Bench (Old Type)
- Bench (New Type)
- Two Bench Marks Consolidated
- Traverse
- Triangulation
- Gravity (Old Type)
- Topographic
- Azimuth
- Reference
- Magnetic

**Face Legends**
Standard bronze station marks of the Coast and Geodetic Survey that are set in concrete or bedrock to serve as a permanent mark for the particular station it represents. Additional information concerning these marks may be obtained by writing to the Director, United States Coast and Geodetic Survey, Washington 25, D.C.

**Know These Marks**
- Vertical (New)
- Horizontal (New)
- Reference (New)
- Traverse
- Triangulation
- Topographic (Old)
- Gravity
- Azimuth

NOAA/PA 73022 (Rev.) 1974
Cutting Edge Surveying Technology circa 1890
Salina, KS Baseline Measurement – 1896
6.5 km/4.1 mi required about 5 weeks
Precision ~ 8 mm/0.03 ft (1:721,600)
Advances in distance measurement technology
Early 1900s
Electronic technology 1950s - 1970
A Game Changer
1984
AN END OF AN ERA
ECHO/PAGEOS BALLOON SATELLITE
TYPE PHOTOGRAPHED BY BC-4
BC-4 CAMERA PHOTOGRAPH
PAGEOS SATELLITE AGAINST THE STAR BACKGROUND
U.S. NAVY NAVSAT TRANSIT SATELLITE “Doppler”
Prototype Launched (Failed) 1959
First Successful Test 1960
Operational 1964 (Military)
Civilian Access 1967
Transit Geoceiver and VLBI

Relative Positional accuracy ~ 0.002 m

Relative Positional accuracy ~ 1 m
The Ellipsoid
Mathematical Model of the Earth

\[ a = \text{Semi major axis} \]
\[ b = \text{Semi minor axis} \]
\[ f = \frac{a-b}{a} = \text{Flattening} \]
The Geoid and Two Ellipsoids

GRS80-WGS84

CLARKE 1866

Earth Mass Center

Approximately 236 meters

GEOID
Ellipsoids Used in the United States

BESSEL 1841
\[ a = 6,377,397.155 \text{ m} \quad 1/f = 299.1528128 \]
(1848 – 1880)

CLARKE 1866
\[ a = 6,378,206.4 \text{ m} \quad 1/f = 294.97869821 \]
(1880 – 1986)

GEODETIC REFERENCE SYSTEM 1980 - (GRS 80)
\[ a = 6,378,137 \text{ m} \quad 1/f = 298.257222101 \]
(1986 – Present)
(International Union of Geodesy and Geophysics Standard)

WORLD GEODETIC SYSTEM 1984 - (WGS 84)
\[ a = 6,378,137 \text{ m} \quad 1/f = 298.257223563 \]
Defined by U.S. Defense Mapping Agency (DMA) for GPS
Global Positioning System

- February 22, 1978 - 1st NAVSTAR Satellite launched
- July 17, 1995 - System Fully Operational
- May 1, 2000 - Selective Availability turned off
- September 26, 2005 - L2C band added
- May 28, 2010 - First L5 Satellite added
- December 23, 2018 – First Block III scheduled for launch
- 2020? - 10-50 cm real-time accuracy! Maybe Sooner!

NO GROUND CONTROL!
Macrometer V-1000 GPS Receiver
1982 ~ approx. $250,000 each
Where are we now??
National Spatial Reference System (NSRS)

Consistent National Coordinate System

- Latitude/Northing
- Longitude/Easting
- Height
- Scale
- Gravity
- Orientation

and how these values change with time

Designed and maintained by NOAA’s National Geodetic Survey
NSRS Control Components

- **Networks of passive geodetic control points**
  - Classical passive survey monuments
  - Approx. 1 million individual horizontal and/or vertical stations published by NGS.

- **National CORS Network**
  - A network of Continuously Operating Reference Stations
  - ~2000+ Active Stations from 239 partner organizations.
NSRS Control Components
NSRS Control Components
EARLY NAD 83 NETWORK PROBLEMS

Not “GPSABLE”

Poor Station Accessibility

Irregularly Spaced

Positional Accuracy
HIGH PRECISION GPS NETWORK (HPGN)
HIGH ACCURACY REFERENCE NETWORK (HARN)
1989 - 1997

“GPSABLE”
Clear Horizons for Satellite Signal Acquisition

EASY ACCESSIBILITY
Few Special Vehicle or Property Entrance Requirements

REGULARLY SPACED
Always within 20-100 Km

HIGH ACCURACY
A-Order (5 mm + 1:10,000,000) (3 5.5 hr sessions)
B-Order (8mm + 1:1,000,000) (2 5.5 hr sessions)

AVERAGE NAD 83 (1986) POSITIONAL CHANGE
0.40 m / 1.3 ft
FEDERAL & COOPERATIVE BASE NETWORKS (FBN/CBN) 
1997 -2004

More State Partnerships

Reduce distortions in early HARNS 
(3-10 cm)

Ensure Connections to CORS

Improve ellipsoid height accuracy 
(Not worse than 2 cm)

No adjustment of old triangulation or GPS if FBN/CBN results were less than 5 cm
NAD 83 (2007)
During 2009-2010 NGS completes multi-year solution of 2000+ CORS

Data from January 1994 to April 2011

Replaced relative GPS antenna calibrations with absolute calibrations

More consistent national set of coordinates Maine to Guam

National adjustment of 81,000+ passive stations to fit new CORS coordinates

Average shift from NAD 83 (2007) to NAD 83 (2011)
National Geodetic Vertical Datum 1929 (NGVD 29)

Original name: “General Adjustment of 1929”
Changed to Sea Level Datum of 1929 in 1940s
Changed to NGVD 29 in 1973

“Zero height” held fixed at 26 tide gauges
Not all on the same tidal datum epoch (~ 19 yrs)

Did not account for Local Mean Sea Level variations from the geoid

Thus, not truly a “geoid based” datum
The National Geodetic Vertical Datum of 1929 is referenced to 26 tide gauges in the US and Canada.
HISTORY OF VERTICAL DATUM IN THE U.S.

NORTH AMERICAN VERTICAL DATUM OF 1988

Use of one fixed height removed local sea level variation problem of NGVD 29

Use of one fixed height did open the possibility of unconstrained cross-continent error build up

The H=0 surface of NAVD 88 was supposed to be parallel to the geoid...(close again)
The North American Vertical Datum of 1988 is referenced to a single tide gauge in Canada.
ELLIPSOID – GEOID RELATIONSHIP

H = Orthometric Height  (NAVD 88)

h = Ellipsoid Height  (NAD 83 (2011))

N = Geoid Height (GEOID12B)

H = h – N

Ellipsoid

Geoid Model

“Average Mean Sea Level” or NAVD 88 Surface

Ellipsoid

GRS80
Types of NGS Geoid Models

Gravimetric (or Gravity) Geoid Height Models (USGG2012, USGG2009)
Defined by gravity data crossing the geoid
  Refined by terrain models (DEM’s)
  Scientific and engineering applications

Composite (or Hybrid) Geoid Height Models (e.g. GEOID12A/B, GEOID09)
  Starts with gravimetric geoid model
  Warped to fit available GPS on BM control data
GEOID 12A/B ACCURACY

http://www.ngs.noaa.gov/web/surveys/GPSonBM/maps/GEOID12A_Accuracy.png
Metadata

Coordinates and heights without appropriate metadata have the same value as a boundary line in Google Earth

Just A Wild A** Guess
METADATA
Data About Data

DATUMS and REALIZATIONS

NAD 27, NAD 83(1986), NAD83 (199X),
NAD 83 (2007), NAD 83 (2011), Epoch xxxx.xx
NGVD29, NAVD88

UNITS
Meters, U.S. Survey Feet, International Feet

ACCURACY
A-Order, B-Order, 1st, 2nd, 3rd, 3cm, Scaled
Examples of Bad Metadata

**BENCHMARK:**

**TOP OF CONCRETE BOUND**
**EL=73.68 GPS DATUM**

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**Supreme Court of the United States**

**No. 5 Orig.**

**United States of America, Plaintiff v. State of California**

**ON BILL OF COMPLAINT**

[December 15, 2014]

Location of the Fixed Offshore Boundary Between the United States and California that is Parallel to the Coastline of Mainland California.

**NAD 83/WGS 84**

**UTM Zone 11 (meters)**

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<th>x-coordinate</th>
<th>y-coordinate</th>
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<tbody>
<tr>
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</tbody>
</table>
Examples of Bad Metadata

National Geodetic Survey,

TV0474 DESIGNATION - SUGAR
TV0474 PID - TV0474
TV0474 STATE/COUNTY - VQ/ST JOHN
TV0474 COUNTRY - US
TV0474 USGS QUAD - WESTERN ST JOHN (1982)

*CURRENT SURVEY CONTROL

TV0474 NAD 83(1997) POSITION - 18 21 05.01515(N) 064 46 38.52774(W) ADJUSTED
TV0474 HORZ ORDER - THIRD

TV0474 DESCRIBED BY COAST AND GEODETIC SURVEY 1918 (OWS)
TV0474 STATION IS OLD STONE SUGAR FAN MILL ON KNOLL JUST W OF DENIS BAY
TV0474 HOUSE.

Height from FEMA Flood Insurance Study = 159.6254 ft (!)
"Local Tidal Datum"
Which tidal datum? - MSL, MLLW, MHW?
What tidal datum epoch?
GOOD COORDINATION BEGINS WITH GOOD COORDINATES

GEOGRAPHY WITHOUT GEODESY IS A FELONY