ACRONYMS US

VLBI
GRS 80
NAD 27
WGS 84
NSRS
CORS
NGVD 29
HARN
NAVD 88
NAD 83
What is a Geodetic Datum?

A set of constants specifying the coordinate systems used for geodetic control, i.e., for calculating coordinates and elevations of points on the Earth. Specific geodetic datums are usually given distinctive names. (e.g., North American Datum of 1983, Old Hawaiian Datum, National Geodetic Vertical Datum of 1929 etc.)

Realized by:

A set of physical monuments with published horizontal and/or vertical coordinates
8 Basic Constants

3 – specify the location of the origin of the coordinate system.

3– specify the orientation of the coordinate system.

2 – specify the dimensions of the reference ellipsoid
Vertical Datums

A set of fundamental elevations to which other elevations are referred.

Datum Types

Tidal – Defined by observation of tidal variations over some period of time
(MSL, MLLW, MLW, MHW, MHHW etc.)

Geodetic – Either directly or loosely based on Mean Sea Level at one or more points at some epoch
(NGVD 29, NAVD 88, IGLD85 etc.)
Network of monument points
(Passive and Active)

Precisely measured in accordance with standardized procedures

Meets Accuracy Standard

Adjusted to tie together

Documented and published for multiple use
The Ellipsoid
Mathematical Model of the Earth

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

GEODE蒂C 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 GEODE蒂C 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
The Geoid and Two Ellipsoids

GRS80-WGS84

CLARKE 1866

Earth Mass Center

Approximately 236 meters

GEOID
Earth-Centered Earth-Fixed (ECEF) Coordinate System

Conventional Terrestrial Pole
1984.0
Bureau International de l'Heure (BIH)
now the IERS

Earth Mass Center

X, Y, Z = 0

X_A, Y_A, Z_A

Greenwich Meridian
3-D Coordinates – Different Expressions

- SPC/UTM
- Greenwich Meridian
- Earth Mass Center
- Equator

- Coordinate systems:
  - \( X_A, Y_A, Z_A \)
  - \( \phi_A, \lambda_A, h_A \)
  - \( N_A, E_A, H_A \)

- Geoid Model
“The Geoid”

An equipotential surface to which gravity is normal and most closely approximates Mean Sea Level over the entire Earth.

So What Do We have??
Ellipsoid – Geoid Relationship

\[ H = \text{Orthometric Height (NAVD 88)} \]

\[ h = \text{Ellipsoid Height (NAD 83 (2011))} \]

\[ N = \text{Geoid Height (GEOID12B)} \]

\[ H = h - N \]
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 is hereby authorized and required, to cause a survey to be taken of the coasts of the United States, in which shall be designated the sounds and bays, and of the shores of any part of the shores of the United States; and into the respective coves and inlets between the principal capes, to be laid down and marked, as he may deem proper, for surveying an accurate chart of any part of the coast, within the limits referred to in the first section of this act.

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, with regard to the shores, rocks, and other objects on shore, and the soundings, and currents beyond the depths referred to in the first section, as his wisdom may, in any case, be deemed necessary, to the commercial interests of the United States.

And be it further enacted, that the president of the United States shall be, and is hereby authorized and required, for any of the purposes aforesaid, to cause proper men in civil and criminal cases; to be employed, and also such of the public officers as are authorized, or by any judge, or the president, or the president or council, or any other person who may be authorized by law, to appoint, for surveying such coasts, as his wisdom shall, in any case, be deemed necessary, to the commercial interests of the United States.

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

The Speaker of the House of Representatives

In witness whereof, I have hereunto signed my name.

[Signature]

John Quincy Adams

Speaker of the House of Representatives

[Signature]

Nathan C. Bedell

[Signature]

Nathan C. Bedell

[Signature]
FERDINAND HASSLER (1770-1843)

Hassler's First Field Work, 1816-1817
What’s In a Name?

1807 - Survey of the Coast

1836 - Coast Survey

1878 - US Coast and Geodetic Survey

1970 – National Oceanic and Atmospheric Administration
National Ocean Service
National Geodetic Survey
24 Inch Theodolite in Hassler’s Camp
Coordinate Origins Prior to 1900

Earliest surveys performed along coast to support nautical charting.

Origins for latitude and longitude by astronomic observations then extended triangulation

December 1866 – Transmission of longitude signals from Valentia, Ireland to Heart’s Content, Newfoundland to Calais, Maine

1871 – 1899 Transcontinental Arc of Triangulation connect east to west
Figure 1
Geodetic Control For 1901 Adjustment - The North American Datum
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.
Wooden Towers
JASPER BILBY
1864-1949
Tower Construction

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

Material:
Lumber -- 5,200 ft
Nails -- 3,000 lbs

Labor:
Skilled workmen -- 2
Common day 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 Geodetic Nomads
1984
AN END OF AN ERA
Satellite Positioning

Soviet Union Launches Sputnik
October 4, 1957
Heroes of Satellite Positioning

Computed First Sputnik Orbits
Johns Hopkins Applied Physics Lab
William Guier
George Weiffenbach
Global Satellite Triangulation Network
(BC-4)
1964-1973
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 ~ 2-5 mm

Relative Positional accuracy ~ 1 m
Space-Based Observations In NAD 83
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
  (12 L5 SVs launched)
- Spring, 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
National Spatial Reference System (NSRS)

Consistent National Coordinate System

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

and how these values change with time
**USC&GS/NGS Marker Types**

**KNOW THESE MARKERS**

- **BENCH** (Old Type)
- **BENCH** (New Type)
- **Two Bench Marks Consolidated**
- **TRAVERSE**
- **TRIANGULATION**
- **GRAVITY** (New 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** (OLD)
- **TRIANGULATION** (OLD)
- **TOPOGRAPHIC** (OLD)
- **REFERENCE** (OLD)
- **GRAVITY** (OLD)
- **AZIMUTH** (OLD)

**FACE LEGENDS**

Standard bronze station marks of the National Geodetic Survey (formerly marks of the Coast and Geodetic Survey) 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: Director, National Geodetic Survey, NOAA, Rockville, Md., 20852.

NOAA/PA 73022 (Rev.) 1974
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
  - ~ 1800+ Active Stations from 239 partner organizations.
NSRS Control Components
NSRS Control Components
24 Horizontal Datums of the US

Bessel Coordinates (1851–1878) – Coordinates derived from locally defined astronomic observations – All computed on the Bessel 1841 Ellipsoid

New England Datum (1879–1900) – First to use Clarke 1866 ellipsoid, origin of coordinates station PRINCIPIO 1845 in Maryland

U.S. Standard Datum (1900–1913)
North American Datum (1913–1927)
North American Datum 1927 (1927–1986)

Alaska Datums (14 Different 1890–1954)
Puerto Rico Datum (1901–1986)
Old Hawaiian Datum (1928–1986)
American Samoa Datum (1962-1993)

North American Datum 1983 (1983–Present) – First to use GRS80 ellipsoid, origin of coordinates at Earth Mass Center

Clarke 1866 ellipsoid
Origin – MEADES RANCH 1891 Kansas

Clarke 1866 ellipsoid
Origin – Local Astro station in each area
Early NAD 83 Network Problems

Stations Not “GPSABLE”

Poor Station Accessibility

Irregularly Spaced

Positional Accuracy
Federal & Cooperative Base Networks (FBN/CBN)  
1997 -2004

More State Partnerships

Remove Distortions in some Early HARNS  
(3-10 CM)

Ensure Connections to CORS

Improve Ellipsoid Height Accuracy  
(Not worse than 2 cm)

Wisconsin Observed – 1997
First national adjustment of all GPS-derived positions for passive stations in the NSRS

Approx. 68,000 stations with GPS observations dating to mid-1980s

Constrained to CORS network who’s positions were considered to be perfect (!)

Can be considered to be identical to NAD 83 (CORS96) – Same as positions from OPUS at that time

Average shift from NAD 83 (1996) to NAD 83 (2007) in WI ≤ 0.02 m
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) in WI \( \leq 0.03 \text{ m} \)
Geodetic Vertical Datums of the US

Sea Level Datum 1929 (1929 – 1973)
Fourth General Adjustment (1912)
Third General Adjustment (1907)
Second General Adjustment (1903)
First General Adjustment (1899) -- (A.K.A. Sandy Hook Datum)

American Samoa Vertical Datum 2002
Puerto Rico Vertical Datum 2002
Northern Marianas Vertical Datum 2003
Guam Vertical Datum 2004
Virgin Island Vertical Datum 2009
1st General Adjustment – 1899

http://docs.lib.noaa.gov/rescue/cgs/003_pdf/CSC-0102.PDF

Appendix 8, pg 283 - 886
2nd General Adjustment – 1903
http://docs.lib.noaa.gov/rescue/cgs/004_pdf/CSC-0107.PDF
Appendix 3, pg 189 - 809
3rd General Adjustment – 1907

http://docs.lib.noaa.gov/rescue/cgs_suppl/QB296U88H391903-1907.pdf
Original name: “Sea Level Datum of 1929”

“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.
## COMPARISON OR VERTICAL DATUM ELEMENTS

<table>
<thead>
<tr>
<th></th>
<th>NGVD 29</th>
<th>NAVD 88</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATUM DEFINITION</td>
<td>26 TIDE GAUGES IN THE U.S. &amp; CANADA</td>
<td>FATHER’S POINT/RIMOUSKI QUEBEC, CANADA</td>
</tr>
<tr>
<td>BENCH MARKS</td>
<td>100,000</td>
<td>450,000</td>
</tr>
<tr>
<td>LEVELING (Km)</td>
<td>102,724</td>
<td>1,001,500</td>
</tr>
<tr>
<td>GEOID FITTING</td>
<td>Distorted to Fit MSL Gauges</td>
<td>Best Continental Model</td>
</tr>
</tbody>
</table>
The North American Vertical Datum of 1988 is referenced to a single tide gauge in Canada.
Height Differences
SLD29/NGVD 29 and NAVD 88
NAVD 88

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

- BM at Father Point (Pointe au Père), Rimouski, Quebec
  Selected because:
  a) It is also the origin of the International Great Lakes Datum of 1985 (IGLD 85)
  b) Height changes in the eastern U.S. would be minimized – this was important to USGS

- The H=0 surface of NAVD 88 was supposed to be parallel to the geoid…(close again)
Types of NGS Geoid Height Models

Gravimetric (or Gravity) Geoid Height Models
(e.g. xGEOID, 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, GEOID09)
- Starts with gravimetric geoid model
- Warped to fit available GPSBM control data
- Defined by legislated geometric datum (NAD 83) and local vertical datum (NAVD 88, PRVD02, etc.)
- May be statutory for some surveying & mapping applications
WORLD GEODETIC SYSTEM 1984

Google “NGA.STND.0036”

Table 2.1, pg 2-4

WGS 84 (G1762) - redefined with respect to the International Terrestrial Reference Frame of 2008 (ITRF2008)
Transform WGS 84 to NAD 83

<table>
<thead>
<tr>
<th>Continent: NORTH AMERICA</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Geodetic Datums</td>
<td>Reference Ellipsoids and Parameter Differences</td>
<td>No. of Satellite Stations Used</td>
</tr>
<tr>
<td>Name</td>
<td>Code</td>
<td>Name</td>
</tr>
<tr>
<td>NORTH AMERICAN 1983 (cont’d)</td>
<td>NAR</td>
<td>GRS 80</td>
</tr>
<tr>
<td>CONUS</td>
<td>NAR-C</td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>NAR-H</td>
<td></td>
</tr>
<tr>
<td>Mexico and Central America</td>
<td>NAR-D</td>
<td></td>
</tr>
</tbody>
</table>

Federal Register Notice: Vol. 60, No. 157, August 15, 1995, pg. 42146
“Use of NAD 83/WGS 84 Datum Tag on Mapping Products”
My Software Says I’m Working in WGS 84

Unless you’re doing autonomous point positioning you’re probably not in WGS 84

Project tied to WGS-84 control points obtained from the Defense Department -- Good Luck!

Use ITRF/IGS coordinates and call them WGS 84

You’re really working in the same reference frame as your control points -- NAD 83?
If I think I really have WGS 84 Coordinates, what should I publish?

Must know which realization

WGS 84 (Transit)
(1987 to June 28, 1994)

WGS 84 (G730) + Epoch of observation
(June 29, 1994 to January 28, 1997)

WGS 84 (G873) + Epoch of observation
(January 29, 1997 to January 19, 2002)

WGS 84 (G1150) + Epoch of observation
(January 20, 2002 to February 7, 2012)

WGS 84 (G1674) + Epoch of observation
(February 8, 2012 to October 15, 2013)

WGS 84 (G1762) + Epoch of observation
(October 16, 2013 to Present)

Which Geoid Model was used
EGM84, EGM96, EGM2008

The epoch (decimal year) of the coordinates:

January 24, 2018 = 2018.066
(24/365 = .066)
Transform WGS 84 to NAD 83

Horizontal Time-Dependent Positioning

TRANSFORMING POSITIONS BETWEEN REFERENCE FRAMES

Specify the reference frame for the input values:

<table>
<thead>
<tr>
<th>NAD_83(2011/CORS96/2007)</th>
<th>(North America plate fixed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAD_83(PA11/PACP00)</td>
<td>(Pacific tectonic plate fixed)</td>
</tr>
<tr>
<td>NAD_83(MAR01/MARP00)</td>
<td>(Mariana tectonic plate fixed)</td>
</tr>
<tr>
<td>WGS_84(original)</td>
<td>WGS_84(transit)</td>
</tr>
<tr>
<td>WGS_84(G730)</td>
<td>(NAD_83(2011) will be used)</td>
</tr>
<tr>
<td>WGS_84(G730)</td>
<td>(ITRF91 will be used)</td>
</tr>
</tbody>
</table>

Specify the reference frame for the output values:

| WGS_84(G730)             | (NAD_83(2011) will be used) |
| WGS_84(G730)             | (ITRF91 will be used)        |
| WGS_84(G1150)            |                              |
| WGS_84(G1674)            |                              |

The decimal point is required but the precision of the fractional year is optional.
The fractional year is obtained by subtracting one from the day-of-year and then dividing the result by 365 (or 366 if it is a leap year).
Thus, the fractional year corresponds to UTC midnight at the beginning of the day.
HTDP models are not valid for dates before the 1980 San Francisco earthquake.

Specify the reference date of the input position(s):

Specify the reference date of the output position(s):

Input the site's position either in terms of latitude, longitude, and ellipsoidal height or in terms of geocentric Cartesian coordinates -X, Y, Z. but not both. For latitude (positive north) and longitude (positive west), use the form degrees, minutes, and seconds and use either commas or spaces to separate the individual values. The field for seconds must include a decimal point. To denote negative values, use negative degrees, minutes, and seconds.

Valid examples for latitude are:
- 37, 34, 35, 67
- 37 34 35.67
- 37.34 35.67 denotes a point in the southern hemisphere.

Values for ellipsoidal height or for X, Y, and Z must be specified in meters and must be entered with a decimal point (but without commas).

Select the type of coordinates to be entered:

- Latitude, Longitude, Height
- X, Y, Z

Latitude or X:
Longitude or Y:
Height or Z:
Station Name (optional):
Coordinates and heights without appropriate metadata have the same value as a boundary line in Google Earth

Just A Wild A** Guess
Datums and Realizations

NGVD29, NAVD88

Units of Measure
Meters, U.S. Survey Feet, International Feet

Accuracy – Horizontal & Vertical
0.03 m, 0.1 ft, 1st-, 2nd-, 3rd- Order etc.
How accurate are values really?
Examples of Bad Metadata

- LE0000 STATION RECOVERY (2013)
- LE0000'
- RECOVERY NOTE BY INDIVIDUAL CONTRIBUTORS 2013
- RECOVERED BY XXXX ENGINEERING COMPANY
- RECOVERED WITH THE FOLLOWING READINGS
- LAT N03x 50' 55.18204782
- LONG W09x 20' 43.56815322
- ELEV 1032.174
- NAD83 IOWA STATE PLANES, SOUTH ZONE, US FOOT
- NORTHING x29889.4330'
- EASTING xx01850.4550'

TOP OF CONCRETE BOUND EL=73.68 GPS DATUM
What can you do to help improve the NSRS?

Download DSWorld
http://www.ngs.noaa.gov/PC_PROD/PARTNERS/index.shtml

Using DSWorld Submit
Updated horizontal positions for scaled BMs with GPS – HH1 or HH2
Submit updated recovery information
Submit digital images

Occupy 1st and 2nd – Order NAVD 88 BMs with GPS
Submit to OPUS Shared Solutions
http://www.geodesy.noaa.gov/OPUS/about.jsp#sharing
GOOD COORDINATION BEGINS WITH GOOD COORDINATES

GEOGRAPHY WITHOUT GEODESY IS A FELONY