Elementary Concepts in Geodesy Pt. I

New York State Association Of Professional Land Surveyors Annual Conference 2014

Presented by

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geolearnn

January 2014
Elementary Concepts in Geodesy
Part I

NYSAPLS Conference
January 2014

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Warning!

• This is not Geodesy 101 in three hours

• It is ABOUT geodesy, with goals to...
  • Understand its relevance to your practice
  • Be more familiar with geodetic terms
  • Understand how work done by geodesists is important to your work
  • Help you to not ignore it
Thanks

• To hardworking NGS professionals
• Many of the information, and slides are used as is or modified from work they have done
  • Doyle
  • Martin
  • Diehl
  • Fromhertz
  • Smith
  • Roman
  • Childers
  • Shields
  • Ikehara
  • Schenewerk
  • Mader
  ...and many more!

Outline

1. Descriptions and definitions
2. Some history
3. Why you cannot ignore geodesy
4. Datums, datums and more datums
5. Why the geoid is important to your professional life
6. Time...who has the time?
7. Integrating geodesy into your practice [get it before it gets you]
1. Description & definitions

- According to the Geodetic Glossary (NGS 2009), geodesy can be defined as
- The science concerned with determining the size and shape of the Earth, or
- The science that locates positions on the Earth and determines the Earth’s gravity field.

Geodesy

- ...the scientific discipline that deals with the measurement and representation of the earth, including its gravitational field, in a three-dimensional time-varying space.
- Geodesists also study geodynamical phenomena such as crustal motion, tides and polar motion.
- For this they design global and national surveying networks, using space and terrestrial techniques while relying on datums and coordinate systems.
Many branches...

- Geometric geodesy: geometric locations, reference ellipsoid; generates geodetic positions (latitude, longitude, height)
- Physical or gravimetric geodesy looks at the Earth’s gravity field
- Satellite geodesy uses orbiting satellites to obtain geodetic data and measure gravity field of earth
- Geodetic astronomy connects ellipsoid to “real” world
- And more...

Plane vs. Geodetic

- In plane surveying, curvature of earth is considered, but only in leveling (whether trigonometric or spirit)
- When plane surveying (horizontal) covers larger and larger areas, depending on required survey accuracy, geodetic measuring and computational procedures must be used
Reference surface (H)

Worldwide reference ellipsoid WGS-84
(World Geodetic System 1984)

- The WGS-84 coordinate system is geocentrically positioned with respect to the center of the Earth. Such a system is called ECEF (Earth-Centered, Earth-Fixed).
- The WGS-84 is a three-dimensional, right-handed, Cartesian coordinate system with its original coordinate point at the center of mass of an ellipsoid.

Reference surface (V)

- Sea level, or more correctly, geoid

http://www.altimetry.info/images/alti/dataflow/processing/ref_surf/ellipsoid.gif
Cartesian coordinates

- Three orthogonal axes (plural of axis)
- Only possible when separation between geoid and (reference) ellipsoid are known, i.e. geoid separation

Growing from plane to geodetic

- Entire country can be surveyed by tying together plane surveys over small extents each
- Unacceptably large distortions occur from ignoring curvature

http://www.georeference.org/doc/images/fig_datum_05.gif
Establish large; move to small

- Better to have net of control (H & V) over entire country established through geometric geodesy
- Then local plane surveys are tied to closest geodetic stations
- As long as the plane surveys are small, they are correctly located (geo-referenced)
- If all small surveys are thus related to geodetic control, then error is controlled
- Just be careful connecting between nearby plane surveys without referencing geodetic control

Networks

- Large spacing to small spacing
- Highly accurate to less accurate (though, in general, lowest order of geodetic accuracy is usually more accurate than most local surveyor accuracy)
- Highest accuracy has widest separation, lowest accuracy geodetic control has smallest separation between points
Geoid

- Think of a surface (imaginary) where the strength of gravity is the same, and it is always normal to the plumb line.
- This surface, when compared to the reference ellipsoid, varies in height with respect to it, it has an irregular shape that undulates, thus this surface (the geoid) is not parallel to the ellipsoid except by accident.

Geop

Geodesy is important

- For the local land surveyor
- Why?

Geodesy’s relevance

- GNSS can’t work without understanding it
- State plane coordinates can only be “black boxed” without it
- GIS is dependent on it
- Merging total station and GNSS data would be difficult, if not impossible without geodesy’s “common platform”
Geodesy’s relevance to others

- Shipping (avoiding reefs, etc., & avoiding dragging bottom, being able to depart from sight of shore)
- Climatology
- Measuring sea level rise (changes due to increase in mean water level and subsidence)
- Glacier monitoring
- Cell phone networks
- Car, ship, plane, pedestrian navigation
- Location-based businesses
- Astronomy
- Geophysics

Position & locations

- Position is coordinates (2- or 3-D)
- Location is place in the real world
- Spatial placement of a location is determined by the position
- We use a coordinate system to determine how to map a particular location
2. Historical earth views

- Flat
- Flat disk (Homer)
- Sphere (Pythagoras, Aristotle)

Size

- Eratosthenes (276-195 BC)
  - Looked in a well at Aswan during summer solstice
  - Measured deviation of sun from zenith on same day at Alexandria
  - Calculated sphere circumference to be 25,000 mi
  - Around equator, we measure 24,902 mi today
  - Around poles 24,860 mi
Others

- Aryabhata (India, in AD 476-550) calculated circumference within 1%
- Muslim scholars AD 830...similar results
- Persians (AD 873-1048), Biruni at age 17 computed circumference with >99% accuracy

A little bit closer in time...

- 18th century: French Academy of Sciences sent expeditions to Lapland and Ecuador for purpose of calculating “geodesic arc”
  - The measurements showed 1:210 flattening, introducing concept of oblate spheroid or ellipsoid
- 19th century work of Everest and others showed deviation of the vertical, introducing term: “undulation of the geoid”
2. Geodesy for you?

- You just cannot ignore it
- GPS requires you to understand it
- Not understanding it dooms you to errors, liability exposure, MISTAKES
- State plane coordinates
- UTM
- GIS
- Like everything else, survey areas get progressively bigger

Yes...it isn’t an option

- Especially if you
  - use GPS
  - publish or use state plane coordinates, UTM, etc.
  - do surveys that have long length or large area
  - are tasked with higher order surveys for special purposes
  - Create or use GIS data (as a surveyor)
It’s like with instruments

- How do you know you got it right?
- An expert needs to be conversant in all aspects of his/her scientific body of knowledge, customs, the art of practicing it
- And yet, many surveyors have trouble staying in the conversation as soon as geodesy, geodetic, etc. come up in the conversation

If you use CORS

- You need to understand some geodetic concepts
If you set up base stations on national control

- You need to at least be conversant with what appears on an NGS datasheet

If you use or publish

- Stuff in NAD83, NGVD88, etc. you better know what you’re getting into
In these days especially...

- Geodetic illiteracy could mean the barrier to financial health

A good test

- Present a 10-15 monologue on geodetic concepts without long pauses
- Must be accurate!
Some necessary background

- How instrumentation works
- Theory of errors
  - Propagation
  - How to apply theory to measurement analysis
- www.ngs.noaa.gov

3. Datums

- Terms: datum, realization, ellipsoid, epoch, projection
- The many flavors of NAD83
- Future datums
- Datasheets, shapefiles
- NGS support, including geodetic advisor program
- Website: www.ngs.noaa.gov
- Dan Martin (VT)
What is a datum?

- ...set of constants specifying the coordinate system used for geodetic control, i.e., for calculating the coordinates of points on the Earth
- ...plus, together with the coordinate system and the set of all points and lines whose coordinates, lengths, and directions have been determined by measurement or calculation.

NAD 27

- ...horizontal control datum defined by (a) location and azimuth on the Clarke spheroid of 1866, with origin at (the survey station) Meades Ranch.
- ... The geoidal height at Meades Ranch (was) assumed to be zero.
- Geodetic positions on NAD27 were derived from the (coordinates of, and an azimuth at, Meades Ranch) through a readjustment of the existent triangulation
NAD 83

- ...horizontal control datum for U.S., Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980.
- ...designated as NAD 83, is the new geodetic reference system.
- ...NAD 83 is based on the adjustment of 250,000 points including 600 satellite Doppler stations which constrain the system to a geocentric origin.

Official U.S. Datums

<table>
<thead>
<tr>
<th>REGION</th>
<th>CONUS</th>
<th>Alaska</th>
<th>American Samoa</th>
<th>Guam</th>
<th>CNMI</th>
<th>Puerto Rico</th>
<th>US Virgin Islands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipsoidal Reference Frame</td>
<td>NAD83 (NSRS 2007)</td>
<td>NAD83 (CORS96)</td>
<td>NAD83 (PACP00)</td>
<td>NAD83 (MARP00)</td>
<td>NAD83 (MARP00)</td>
<td>NAD83 (CORS96)</td>
<td>NAD83 (CORS96)</td>
</tr>
<tr>
<td>Vertical Datum</td>
<td>NAVD88</td>
<td>NAVD88</td>
<td>ASVD02</td>
<td>GUVD04</td>
<td>NMVD03</td>
<td>PRVD02</td>
<td>VIVD09</td>
</tr>
</tbody>
</table>

- NAVD88 - NORTH AMERICAN VERTICAL DATUM OF 1988
- ASVD02 - AMERICAN SAMOA VERTICAL DATUM OF 2002
- GUVD04 - GUAM VERTICAL DATUM OF 2004
- NMVD03 - NORTHERN MARIANAS VERTICAL DATUM OF 2003
- PRVD02 – PUERTO RICO VERTICAL DATUM OF 2002
- VIVD09 – VIRGIN ISLANDS VERTICAL DATUM OF 2009 –pending adoption
Horizontal datums

- Only!
- NAD 27
- NAD 83

Vertical Datums

- NGVD 29
  - 26 tide gages, U.S. & Canada
- NAVD 88
  - Fixed on one point: Father Point/Rimouski, Quebec, Canada
  - VERTCON can be used to convert
  - ±2 cm, one sigma
WGS 84

- World Geodetic System of 1984
- Reference frame used by (DoD); defined by National Geospatial-Intelligence Agency (NGA), (formerly the National Imagery and Mapping Agency) (formerly the Defense Mapping Agency)
- WGS 84 is used by DoD for all its mapping, charting, surveying, and navigation needs, including its GPS "broadcast" and "precise" orbits
- WGS 84 was defined in Jan 1987 using Doppler satellite surveying techniques. It was used as the reference frame for broadcast GPS Ephemerides (orbits) beginning January 23, 1987.

WGS 84 / 2

- At 0000 GMT Jan 2, 1994, it was upgraded in accuracy using GPS measurements. The formal name then became WGS 84 (G730) since the upgrade date coincided with the start of GPS Week 730. It became the reference frame for broadcast orbits on June 28, 1994.
- At 0000 GMT Sep 30, 1996 (start of GPS Week 873), WGS 84 was redefined again and was more closely aligned with International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) 94. Now called WGS 84 (G1150)
Changing the Datum

The grid shifts uniformly (mathematically) in any one region.
Everything gets a New coordinate!
1927-1983: up to 100's of meters
1983-2022: 1-2 meters

Adjusting Coordinates within the Datum is a new realization

Modifying each point for its "issues": change is not uniform/constant everywhere
1) Actual Motion/Velocities
2) Error correction/Old data
3) New Information/Obs
On the order of centimeters
Done regularly: Next 2012
Realizations

1. (86) –original, pre-GPS data
2. (92) for California; for other states (9#)
3. (CORS96)
4. (98) in CA
5. (NSRS2007) or (2007)
6. (2011)
7. Future: ~2022

All on same datum

What’s the same, what’s different?

- Same reference ellipsoid: GRS80 for each datum NAD83, WGS84, and ITRF## or IGS##
- Difference in datums is location of origin (center)
- NAD83(#) is the datum tag, represents an adjustment, either national or by state
- Difference is the dataset of which geodetic control points used as constraints
- Difference could be epoch date of coordinates
What’s in a name?

- Coordinate system as used in geodesy: “coordinate system” (ISO terminology).
- International geodetic organizations like the IERS (International Earth Rotation and Reference Systems Service) speak of a “reference system.”
- When these coordinates are realized by choosing datum points and fixing a geodetic datum, ISO uses “coordinate reference system,” while IERS speaks of a “reference frame.”
- A “datum transformation” is referred to by ISO as a “coordinate transformation.”

Q & A
**About the seminar presenter**

**Joseph V.R. Paiva, PhD, PS, PE**

Joseph V.R. Paiva is CEO of GeoLearn, LLC (www.geo-learn.com), which is launching an online professional education business for the geospatial industry in early 2014. Joe started this business with his partner Bob Morris, whose most recent global industry position was President of Leica Mapping. Previously, Dr. Paiva was CTO of SADAR 3D and COO of Gatewing NV, a Belgian unmanned airborne systems company. Prior engagements in consulting were in the field of geomatics and general business, particularly to international developers, manufacturers and distributors of instrumentation and other geomatics tools. Dr. Paiva and Mr. Morris continue to be involved in consultancy through a separate partnership called GeoSpatial Associates, LLC will continue this consultancy. Joe’s career includes: managing director of Spatial Data Research, Inc., a GIS data collection, compilation and software development company; various assignments at Trimble Navigation Ltd. including senior scientist and technical advisor for Land Survey research & development, VP of the Land Survey group, and director of business development for the Engineering and Construction Division; vice president and a founder of Sokkia Technology, Inc., guiding development of GPS- and software-based products for surveying, mapping, measurement and positioning. He has also held senior technical management positions in The Lietz Co. and Sokkia Co. Ltd. Prior to that was assistant professor of civil engineering at the University of Missouri-Columbia, and a partner in a surveying/civil engineering consulting firm. He has continued his interest in teaching by serving as an adjunct instructor for online course development and teaching at the Missouri University of Science and Technology. His key contributions in the development field are: design of software flow for the SDR2, SDR20 series and SDR33 Electronic Field Books and software interface for the Trimble TTS500 total station. He is a registered Professional Engineer and Professional Land Surveyor, has served as ACSM representative to the Accrediting Board for Engineering and Technology (ABET), serving as a program evaluator, team chair, and commissioner and has more than 30 years experience working in civil engineering, surveying and mapping. He writes for *POB*, *GeoDataPoint* and *The Empire State Surveyor* magazines and has been a past contributor of columns to *Civil Engineering News*. Joe has also been a consultant to the Geomatics Industry Association of America, later reorganized under the Association of Equipment Manufacturers (AEM) as the Geospatial Industry Group, Joe has organized and presented workshops and authored and edited articles for the technical press in this role.

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