

Part II – Benefits of a Standard
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Introduction – while somewhat anecdotal, much of the following information is relevant:

Efficiencies in practice can often be improved by bringing disparate methods under the umbrella of common procedures, identified as a standard. The presumption is that benefits realized by adopting and using a standard ultimately justifies development of the standard. The goal in this article is to highlight the benefits of and to promote the 3-D global spatial data model (GSDM) as a standard.

As in other arenas, applications of spatial data benefit from “checks/balances” when following a prescribed standard versus adopting new or independent procedures. Existing standards support productive efforts and efficient operations in many practices. On the other hand, disruptive innovation and competition drive the quest for improvement. New procedures need to be discussed, tested, and proven before modifying or supplementing existing standards.

In particular - separate horizontal and vertical datums are the foundation for many spatial data applications. Those models/procedures have evolved over time and have been enormously beneficial. The fact that horizontal and vertical datums have disparate geometrical origins is a challenge addressed by geoid modeling. Although geoid modeling can be expensive and somewhat cumbersome, those processes are used extensively. The GSDM defines a single origin for 3-D data.

The digital revolution, and the associated analog/digital transition, directly impacts collection, storage, manipulation, display, and use of spatial data. The Earth-centered Earth-fixed (ECEF) system used worldwide since being developed by the U.S. military more than 50 years ago for tracking satellites in orbit serves as a primary reference for spatial data. It consists of 3 mutually perpendicular axes having an origin at Earth’s center of mass (CM). The X/Y axes lie in the plane of the equator, and the Z axis is parallel with the Earth’s spin axis. Rules of solid geometry, vectors, and matrix algebra support efficient spatial data computations in 3-D space. Collectively these features form the basis of the GSDM – see <http://www.globalcogo.com/gsdmdefn.pdf>. The GSDM also provides concise mathematical definitions for network and local accuracies as part of error propagation computations (stochastic model). It appears that the GSDM will have a long shelf life.

The huge take-away is that the ECEF system provides an integrated worldwide 3-D datum which accommodates subordinate use of separate horizontal and vertical datums (if properly defined). But old habits die hard and exploiting the benefits of a 3-D datum will occur incrementally. The transition needs to be supported by careful analysis and discussions of issues such as those listed in [Part-I](#).

Particulars:

1. Professionals and staff at the National Geodetic Survey (NGS) are to be commended for developing the modernized National Spatial Reference System ([NSRS](#)). Appropriately applauded by the professional community, that project will spawn enormous (maybe even worldwide) benefits. Even so, some spatial data end users remain skeptical of using methods containing unneeded approximations and distortions. While development of geoid models is impressive, using ellipsoid heights for the third dimension will greatly reduce the need for geoid modeling and “using a 3-D model for 3-D data” obviates the need for low-distortion projections.

2. Notwithstanding the account in Genesis, Chapter 11, of the Holy Bible, there are many benefits to be realized in using or following a common standard (model) for given activities.
3. The overall topic of standards is quite large. This article focuses on a small, but important, segment addressing a 3-D digital spatial data standard within the ECEF environment.
4. Relativity and the curvature of space/time are not included in the GSDM. Those impacts are handled by others responsible for converting raw observations into spatial data components.
5. All GSDM equations and procedures are in the public domain and are applicable for any given epoch of ECEF values. Transformation of ECEF values from one epoch to another and between reference frames is discussed in NOS NGS 67, Part III – Blueprint for Modernizing the NSRS. As such, those procedures, based on ECEF values, are compatible with the GSDM.
6. The GSDM involves little or no new science. What’s new is beginning with the assumption of a single origin for 3-D spatial data and building a spatial data model using existing rules of mathematics and logic. The “new” challenge is execution.
 - a. In addition to innovative civilian applications (e.g., autonomous navigation and/or returning a rocket booster to the launch pad), modern warfare is a huge arena for testing and implementing spatial data concepts/practices. Those state-of-the-art applications are becoming routine, and the benefits are permeating civilian practice. For example, see the 2014 movie “Eye in the Sky” and the recent 3-D "[rocket booster catch](#)" by SpaceX.
 - i.) Navigating (The concepts of location, acceleration, motion,
 - ii.) Targeting gravity, logic, and logistics are fundamental to
 - iii.) Collision avoidance understanding results reported in daily news.)
 - b. The full impact of AI is yet to be realized. Undoubtedly many will benefit from using AI in ways yet unknown. However, several warning flags deserving attention include. . .
 - i.) The need for algorithmic justice is discussed in a book, “AI Unmasked” by Joy Buolamwini (2023). Credible inputs from and studies by NIST are cited.
 - ii.) A parallel circumstance applies for spatial data applications where the criterion centers on algorithmic integrity. Using a common 3-D spatial data standard, embedded in AI apps, will help eliminate ambiguities such as. . .
 - What elevation is to be associated with a horizontal distance?
 - Are reported (and archived) results based on true 3-D or pseudo 3-D?
 - Is relative accuracy defined by an error ellipse or by standard deviation?
 - c. Computational efficiencies can be enhanced to the extent users exploit features of a common standard 3-D spatial data model – for overview of example, see 3-D [diagram](#).
 - i.) Primary ECEF values (coordinates and covariances) – Box 1 of 3-D diagram (For format example - see <http://www.globalcogo.com/dbformat.html>.)
 - ECEF values for location, X/Y/Z.
 - Covariance values for designated point (optional).
 - Correlation between points (optional).

- i.) Geodetic latitude, longitude, and height are computed from X/Y/Z values.
- ii.) Point-to-point computations are based on coordinate differences.
- iii.) A rotation matrix is used to change a geocentric perspective to a local perspective.
 - Convention: a directed line segment is “there – here, point 2 – point 1, or forepoint – standpoint,” e.g., $\Delta X = X_2 - X_1, \Delta Y = Y_2 - Y_1, \Delta Z = Z_2 - Z_1$.
 - Changing between geocentric & local perspectives occurs at point 1 using bi-directional rotation matrices, see www.globalcogo.com/PG002.pdf.
 - The resulting $\Delta e, \Delta n, \Delta u$ components are identical to “flat-Earth” surveying.
- iv.) Point to point computations (“there” minus “here” or pt2 minus pt1) include:
 - 3-D spatial distance in either geocentric or local perspective.
 - Distance = $\sqrt{(\Delta X^2 + \Delta Y^2 + \Delta Z^2)} = \sqrt{(\Delta e^2 + \Delta n^2 + \Delta u^2)}$.
- v.) Flat-Earth local horizontal distance, HD = $\sqrt{(\Delta e^2 + \Delta n^2)}$. Other HD options exist.
- vi.) The true 3-D geodetic azimuth “here to there” (or Pt₁ to Pt₂) = $\text{atan}(\Delta e/\Delta n)$.
- vii.) The back azimuth uses the same equation with Δe and Δn computed at forepoint.
- viii.) Difference in elevation is easily computed. . .
 - True 3-D: difference in elevation = $h_2 - h_1$.
 - Pseudo 3-D: difference in elevation = Δu .

7. Philosophical considerations include:

- a. Efficiencies are realized by following and using a stated standard.
- b. Consequences involving waste/duplication can be avoided using a standard.
- c. Meta data are critical and should be included in the standard.
- d. Acknowledgement – sometimes, documenting what procedures were used may be more important than claiming compliance with a given standard.

8. By comparison, the claim is that the GSDM. . .

- a. Supports rigorous 3-D spatial data computations for all disciplines worldwide.
- b. Enables a user to track the accuracy of data and to know “with respect to what?”
- c. Is less complicated than using traditional map projection procedures.
- d. Provides a better path from observations/measurements to useful solutions.
- e. Obviates the need for geoid modeling and low-distortion projections.
- f. Is sufficiently flexible to accommodate legacy spatial data components.
- g. Gives the end user a tool for numerically filtering data from a database.
- h. Provides efficient methods for adding points to the 3-D database. But note. . .
(Optional covariance values for each point can define the quality of data added.)

9. The origin for elevation is arbitrary but it should be stable, observable, and repeatable. Earth’s CM is more stable and easier to locate than the geoid. Ellipsoid heights (and height differences) are derived from ECEF coordinates and can be used reliably to answer the questions:

- a. What is the height of this point with respect to other (nearby) points?
- b. What is the height of this point with respect to where it was previously?
- c. What is the geoid slope between points with respect to the ellipsoid normal?
(If needed, deflection-of-the vertical can provide a correction to ellipsoid-derived slope.)

10. Hydraulic grade lines are readily approximated by ellipsoid height differences. Admittedly there may be occasions requiring a better approximation. (For rigorous applications over large areas, hydraulic gradients are determined from dynamic heights, not orthometric heights.) If needed, corrections to an ellipsoid-derived gradient to obtain a geoid-based gradient can be obtained

from deflection-of-the-vertical values. A discussion of the impact of gravity on practical spatial data applications is posted at <http://www.globalcogo.com/ImpactOfGravity.pdf>. Even so, on-going scientific research reveals that there is much yet to be learned about gravity. For example, do an internet search on “curvature of space/time and gravity.”

11. With publication of the modernized NSRS, the elevation of all published 3-D points will change. Using ellipsoid heights for the third dimension will serve the public and avoid the cost and inconvenience of incorporating “updated” geoid models at a later time. Updating a geoid model without revising underlying X/Y/Z coordinates can create unwanted problems. A case in point is described at <http://www.globalcogo.com/VariousGeoids.pdf>.

Examples – models and standards development:

1. According to Wikipedia, the Rosetta Stone, found in 1799 in the Nile Delta, was carved several hundred years BC and contains 3 linguistic versions of the same text. Discovery of this “standard” significantly enhances current scholars’ ability to understand early civilization.
2. Gerard Mercator (1512 – 1594) never traveled far from home yet he created global maps.
 - a. Mercator compiled and integrated information from many sources.
 - b. Mercator’s crowning achievement was his World Map of 1569.
 - c. The spacing of parallels related to distortion became known as a conformal map.
 - i.) A conformal map can be used to sail a constant bearing across the ocean.
 - ii.) Scale distortion on a conformal map is the same in all directions at a point. This feature is important for map projections used for state plane coordinate systems.
 - d. Limitation – a map projection is strictly 2-D. Modern spatial data applications are 3-D.
3. Meridian surveys were used to compute the size and shape of the Earth.
 - a. Early determinations presumed the Earth to be a sphere - Eratosthenes and others.
 - b. Jean-Dominique (1625-1712), Director of Paris Observatory concluded Earth is prolate.
 - c. Newton (1642-1727) argued that the Earth is oblate due gravity and centrifugal force.
 - d. French Academy of Science sponsored meridian surveys to settle the dispute.
 - i.) 1636-1637 a 2-year survey in Lapland showed the Earth to be oblate.
 - ii.) 1635-1641 a 7-year expedition to Peru confirmed findings of the Lapland survey.
4. Solving the problem of finding reliable longitude at sea evolved over time. **Dava Sobel’s book, “Longitude”** (Wikipedia et.al.) gives a fascinating story of a clockmaker’s (Harrison’s) invention.
 - a. Easy – latitude at sea was estimated from the observed altitude of the sun (and stars).
 - b. Finding longitude at sea was much more difficult. In October 1707 four of five British warships sank and lives of nearly 2,000 troops were lost due to navigational error.
 - c. Under pressure from the user community, Parliament passed the Longitude Act in 1714.
 - d. The Act provided a prize for finding longitude at sea - ultimately won by a clockmaker.
 - e. In 1736 Harrison’s first version, H1, was field tested on a run to Lisbon, Spain.
 - f. Although the test was largely successful, Harrison insisted on making improvements.
 - g. It became a test of wills/methods - Harrison’s clocks versus astronomical observations.
 - h. The final version, H4, out-performed expectations and final payment was made in 1773.
5. Inequity in weights and measures contributed to conditions underlying the French Revolution. **(See “A Measure of All Things,” Ken Alder 2002, The Free Press, New York, London, etc.** The meter issue is more consequential than “true 3-D” vs “pseudo 3-D,” but there are parallels.)

- a. The solution included standardizing units of measure – length being one of them.
 - b. A case was made that a length standard should be reproducible and globally applicable.
 - c. A “better” survey of the Earth’s quadrant was conducted between 1792 and 1799.
 - i.) The surveyed quadrant distance was set to equal 10,000,000 meters.
 - ii.) A provisional meter bar was sent to the U.S.A. in 1794 and is preserved at NIST.
 - iii.) Final platinum bar was accepted in 1799. Iron copies presented to foreign savants.
 - iv.) Subsequent issues/discussions were settled at the “1875 Convention of the Meter” – see discussion posted by Wikipedia.
6. The Greenwich Meridian has served as the Prime Meridian (0° longitude) since 1884:
- a. “Greenwich Time,” Derek Howse, 1980, Oxford University Press, Oxford, New York etc.
 - b. A quote from the 1884 International Meridian Conference, Washington, D.C. is . . .
 “It is the opinion of this Congress that it is desirable to adopt a single prime meridian for all nations, in place of the multiplicity of initial meridians which now exist.”
 - c. Of alternatives considered, Greenwich won based on shipping tonnage of users.
 - d. Note: Spain agreed to vote for Greenwich if U.S. and Britain adopted the metric system.
7. Horizontal and vertical datums in the United States have served the end user for many years.
- a. Datums are defined and supported by the NGS – for a brief history see, [U.S. Datums](#).
 - b. NAD 27, horizontal only, was defined in meters but accommodates the U.S. Survey Foot
 - c. NAD 83, horizontal (2-D/3-D), also metric but accommodates the International Foot.
 - d. 2022 datum components – [4 horizontal datums and 1 vertical datum](#)
 - i.) NATRF2022, 3-D horizontal datum, North American Terrestrial Reference Frame.
 - ii.) PATRF2022, 3-D horizontal datum, Pacific Terrestrial Reference Frame.
 - iii.) MATRF2022, 3-D horizontal datum, Mariana Terrestrial Reference Frame.
 - iv.) CATRF2022, 3-D horizontal datum, Caribbean Terrestrial Reference Frame.
 - v.) NAPGD2022, 1-D datum, North American-Pacific Geopotential Datum of 2022.
 - e. The horizontal datums are 3-D datums defined in terms of ECEF coordinates.
 - f. The geoid is the origin for the vertical datum instead of Earth’s CM. Origins are disparate.
8. International Foot.
- a. The meter has been the official standard of length in the U.S. since 1866.
 - b. The NGS has always worked in the meter but has supported “foot” units in practice.
 - c. After WWII the NATO countries collaborated on building military equipment.
 - d. Machining tolerances for aircraft engines created problems due to conversions:
 - i.) England: 1 inch = 2.539997 cm
 - ii.) Canada: 1 inch = 2.540000 cm
 - iii.) United States: 1 inch = 2.540005 cm
 - e. At the 1959 Conference on Weights & Measures, the United States and Great Britain, reached a compromise on the Canadian unit. The International Foot is 1 inch = 2.54 cm.
 - f. This and other policies give witness to the importance of having and using a standard.
9. Space X and reusing rocket boosters.
- a. ChatGPT and Walter Isaacson in his book, “Elon Musk” both credit Elon Musk with:
 - i.) Going back to first principles and establishing a reason for an action.
 - ii.) Discarding unproven methods/procedures.
 - b. An example of Musk’s efforts (using 3-D) can be seen at www.tru3d.xyz/catch.pdf.

Forward Looking:

1. A global standard for 3-D spatial data will be beneficial to all users.
 - a. It will fill the gap between X/Y/Z values, local (flat-Earth) use, and archived data.
 - b. A spatial data model will accommodate both rigorous procedures and “simple” use.
 - c. Spatial data accuracy feature (optionally) answers the question “with respect to what?”
 - d. No distortion of map elements but gives answers based on assigned standard deviations.
 - e. The quality of data drawn from a database is selectable by the user in choosing a filter.
 - f. The quality of data added to a database needs to meet “standard input specifications.”
 - g. The stochastic model accommodates any standard deviation (variance) provided by user.
2. Spatial data disciplines worldwide will enjoy benefits achieved by using a common standard.
 - a. Governmental
 - b. Commercial
 - c. Professional
 - d. Technical
3. Standards organizations may eventually embrace 3-D global spatial data standard – the following list was generated with the assistance of AI (ChatGPT).
 - a. ISO
 - b. ASTM
 - c. FGDC
 - d. ASCE
 - e. ASPRS
 - f. Standards and Specifications for OPUS Projects - NOS NGS 92, October 2024

Concise summary of issues:

1. A 3-D datum is . . .
 - a. Applicable worldwide.
 - b. Mathematically superior.
 - c. Logistically more efficient.
 - d. Already defined and in place.
 - e. Compatible with AI implementation.
 - f. Being used in innovative applications.
2. Historical practice utilizes separate horizontal and vertical datums.
 - a. Impressive infrastructure and civil works projects are based on separate datums.
 - b. Geoid modeling is required to reconcile geometrically disparate origins.
3. The user community is heavily invested in established practices.
 - a. Pseudo 3-D and elevations are fundamental aspects of hydrologic modeling.
 - b. Precedent carries enormous clout, but disruptive innovation will define future use.
 - c. Innovative applications rely more and more on true 3-D. The GSDM includes. . .
 - i.) Geometry and functional model.
 - ii.) Stochastic model – error propagation.
 - d. Algorithmic integrity is essential in AI applications.

4. Ellipsoid makes a better reference for vertical than does the geoid because Earth's CM is. . .
 - a. More stable.
 - b. Easier to locate.

5. A map projection is a 2-D model and involves some level of distance distortion.
 - a. State plane coordinates.
 - b. Low distortion projections.
 - c. A conformal projection satisfies Cauchy Reiman transformation equations.

6. Water flows are driven by hydraulic grade.
 - a. Grades can be approximated by differences in ellipsoid height
 - b. Corrections based on deflection-of-the-vertical are available if needed.
 - c. Dynamic heights are used in critical cases over large areas.

7. Obstacles.
 - a. Past practice – see AT&T link at the end.
 - b. Elevations at the coast and in Death Valley - below sea level.

8. Numbers will change with publication of modernized datum:
 - a. Adopting 3-D datum ellipsoid heights now will avoid confusion and future transition.
 - b. Unpopular as it may be, this is an excellent opportunity to “go metric.”
 - c. People can and do change. I may even buy an electric car sometime.

9. Impact related to field procedures.
 - a. Observations are independent while measurements may be correlated.
 - b. Corrections for known physical circumstances are applied to eliminate systematic errors.
 - c. Layout – corrections used when “tying-in” are applied in reverse.
 - d. The positional quality of lay-out (staked position) is determined by tying it in (again).

Impact of 3-D:

1. Some will not take Information contained in this document seriously because. . .
 - a. The current system works and is reliable.
 - b. A credible case has not been made for making the transition to true 3-D.
 - c. Too much is invested in geoid modeling. It would be a shame to discard that investment.
 - d. Many have proprietary interests in current practice and don't wish to change.
 - e. The software needed for 3-D practice is not yet conveniently (economically) available.
 - f. Clients don't want it or need it. Disruptive innovation is the prerogative of others.
 - g. Making the transition from pseudo 3-D to true 3-D would cost too much.
 - h. The resources needed to “retrain” self, staff, associates, or clients are prohibitive.
 - i. The claim is that orthometric heights are needed to determine which way water will run.
 - j. The “will” to develop justification for transition to true 3-D has yet to be developed.
 - k. Current work is conducted using traditional practices, obviating the need to switch.

2. Information contained in this document should be taken seriously because. . .

The 3-D Genie will never return to the bottle, see www.globalcogo.com/ATandT-Story.pdf