Implementing the GSDM – Part I, Part II, Building, and Common

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This document, posted at http://www.globalcogo.com/Implementation.pdf, aggregates:

1. Summary of historical and chronological development of the geometry and justification for the global spatial data model (GSDM) – Part I, posted at http://www.globalcogo.com/Part-I.pdf.

2. Description of the benefits of adopting a model (standardization) for 3D spatial data along with examples of standardization efforts – Part II, posted at http://www.globalcogo.com/Part-II.pdf.

3. An article that shows how Parts I and II above build on two excellent articles by Dr. N. W, J, Hazelton describing the implications of the digital revolution for current geospatial developments – http://www.globalcogo.com/Building.pdf.

4. The GSDM provides an arena for exchange of 3D spatial data between spatial data generators and users in a common "standardized" format – article posted at http://tru3d.xyz/common.pdf.

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3D Digital Spatial Data, Time is 4th Dimension – Part I

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Convergence of abstraction/technology/policy/practice fosters a discussion of issues.

1. The digital revolution is driving the transition to the use of 3D digital spatial data.

2. The geocentric Earth-centered Earth-fixed (ECEF) coordinate system is the primary reference.
   a. The origin is at Earth's center of mass (CM).
   b. Location anywhere in the world or near space is defined by rectangular X/Y/Z coordinates.

3. Rules of geometry do not change and include both solid geometry and plane geometry.

4. Mathematical relationships between rectangular and curvilinear systems are unambiguous.

5. Gravity is one of four fundamental physical forces and is. . .
   a. The subject of extensive research by the National Geodetic Survey (NGS) and others.
   b. Too small at atomic scales to be part of the standard model of particle physics.
   c. Infinitely large in regions of space known as black holes.
   d. Everywhere present in human experience in, on, or near the Earth.
   e. Manifest in "deflection-of-vertical," the difference between a plumb line and the normal.
   f. The reason for the difference between spatial data and geospatial data.

6. In the hierarchy of classifications,
    a. Although sometimes overlooked, a fundamental question is, "with respect to what?"
    b. Spatial data describes shapes and location of objects, typically rectangular flat earth.
    c. Geospatial data are spatial data that are referenced to the Earth – often curvilinear.
    d. In the context of mathematics, geospatial data is a subcategory of spatial data.
    e. In the context of geography, spatial data is a subcategory of geospatial data.

7. Spatial data and geospatial data both exist in three dimensions and can be reconciled.
    a. Horizontal data are 2-dimensional as experienced by walking erect on a "flat Earth." (Definitions of horizontal distance (HD) can be mathematically ambiguous.)
    b. Specificity for HD is assured by using a defined horizontal datum. (A simple widely used definition of HD is the right triangle component of a slope distance.)
    c. Vertical data are 1-dimensional, perpendicular to horizontal, and parallel to. . .
        i.) The plumb line at a point. It is called elevation or orthometric height.
        ii.) The ellipsoid normal. It is called ellipsoid height or geodetic height.
        iii.) The difference between normal and plumb line is due to gravity – item 5.e above.
        iv.) Unlike normals, plumblines at the bottom & top of a tall skyscraper are not parallel.
    d. Characteristics of spatial data are supported by separate horizontal and vertical datums.
    e. An integrated 3D datum supports true 3D while pseudo 3D uses elevation, not height.

8. The digital revolution is driving convergence of abstraction/technology/policy/practice.
    a. Traditional practice implements horizontal and vertical datums separately.
    b. The NGS has a long history of providing end users reliable control coordinates for. . .
        i.) Horizontal: latitude and longitude on NAD 27, NAD 83 etc.
        ii.) Vertical: elevations referenced to mean sea level, NGVD 29, NAVD 88 etc.
    c. The U.S. DoD and the scientific community have separately defined. . .
        i.) The WGS 84 ECEF reference system worldwide.
        ii.) The ITRF ECEF reference system worldwide.
    d. Both are monitored and compared daily. The differences are statistically insignificant.
    e. NAD 83 uses the GRS 80 ellipsoid and is tied to the global network at a given epoch.
    f. The Earth is dynamic and gradual changes in the global network are monitored/modeled.
    g. The location of Earth's center of mass (CM) is known better now than in the past due to. . .
        i.) Different and improved instrumentation.
        ii.) Larger data set - accumulation of observations over a longer period of time.
        iii.) Transfers of mass on, in, or near the Earth – earthquakes, melting of ice cap, etc.
    h. The NAD 83 is referenced to a static location of the CM, WGS 84 is updated more often.
    i. The NGS is modernizing (updating) our National Spatial Reference System (NSRS).
        i.) See www.ngs.noaa.gov (new datums) for information on replacing datums.
        ii.) Tectonic plate motions and other movements will be modeled.
        iii.) Earth's CM will be more closely aligned with WGS 84.
        iv.) The new datum will be 3D, but a separate vertical datum will also be published.

9. Which leads to the question, "Under what circumstances will the spatial data user community be better served by using a 3D datum rather than separate horizontal and vertical datums?"
    a. Stakeholders should be discussing spatial data issues and developing policies.
        i.) International agencies. A complete list would include all who use spatial data.
            - United Nations.
            - International Standards Organization.
            - Others.

ii.) Federal agencies. A complete list would include all who use spatial data.
  - National Institute of Standards and Technology.
  - National Geospatial Intelligence Agency.
  - National Geodetic Survey.
  - United States Geological Survey & Federal Geographic Data Committee.
  - Others (NASA, FHWA, FEMA, FAA, NSF, etc.).

iii.) Professional associations. A complete list would include all who use spatial data.
  - World Geospatial Industry Council
  - American Society of Civil Engineers
  - American Society of Photogrammetry & Remote Sensing
  - National Society of Professional Surveyors
  - Others (NCEES, aerospace, unmanned vehicles, etc.).

iv.) Other organizations. A complete list would include all who use spatial data.
  - Manufacturers, vendors, and service providers.
  - City, county, state, and agencies.
  - Utilities, independent commissions,
  - Corporations, businesses, consultants.
  - Consumers (Should the list include everyone who uses a cell phone?)
  - Others.

b. Topics to be discussed related to using a 3D datum include:

i.) Technical. . .
  - Geometry – true 3D versus pseudo 3D.
  - Gravity – relative/absolute, coverage (local, regional, global etc.).
  - Modeling – trade-off between adequate/simple (tolerances).
  - Spatial data accuracy (with respect to what?).

ii.) Administrative/legal. . .
  - Responsibility and enforcement.
  - Legislative – various levels
  - Intellectual property issues.
  - Education, promotion, permanence/sunset.

iii.) Economic/political. . .
  - Consequences and cost of not adopting 3D.
  - Benefits (to various sectors of global economy).
  - Capitalization and development of timelines for transition.
  - Budgeting/cost recovery.

iv.) Policy
  - Standards
  - Contracts

v.) Practice
  - Specifications
  - Common procedures
  - Interoperability

10. Spatial Data Models

a. Characteristics – a "universal" spatial data model should be. . .

i.) Applicable worldwide.

ii.) Appropriate for use by all spatial data disciplines.

iii.) Immediately and readily available.

iv.) Rigorous and Simple.

v.) Transparent with all equations in the public domain.
vi.) Able to track spatial data accuracy.
vii.) Adopted as the standard for moving 3D spatial data epoch to epoch.
viii.) Compatible with the concept of digital twins.
ix.) Supportive of definition and use of high-definition maps.
x.) The undisputed foundation for AI applications involving use of spatial data.

b. The Global Spatial Data Model (GSDM):
   i.) Was formally defined in 1997 - http://www.globalcogo.com/gsdmdefn.pdf
   ii.) Fulfills all characteristics in "a" above – especially for spatial data accuracy.
   iii.) Emerged from abstractions considering applications of technology.
   iv.) Has survived repeated challenges in technical literature.
   v.) Enables digital transition not unlike experiences of AT&T and Kodak.
   vi.) Greatly reduces the need for geoid modeling and low-distortion projections.
   vii.) Has an infinite shelf-life, avoiding obsolescence.

c. Considerations – impact:
   i.) With the publication of the new 3D datum, elevations will change.
   ii.) With few exceptions, elevation can be approximated by ellipsoid height.
   iii.) Corrections, like equation-of-time and polar motion, can be used if needed.
   iv.) User-selected "filter" can be applied to values drawn from 3D database.
   v.) A "3D model for 3D data" will obviate the need for low-distortion projections.
   vi.) Algorithmic justice/integrity is needed – www.globalcogo.com/3D-and-AI.pdf.
   vii.) Existing datum values will become "legacy" – similar to the successful deprecation of the U.S. Survey Foot.

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Part II – Benefits of a Standard

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1. Fix typos and relabeled paragraphs using outline format – December 5, 2024.
2. Added example **III.J of "Common" Point for Data Exchange** – 12/05/2024.
3. Revised line spacing format and incidental typo corrections – May 19, 2025.

I. 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 justify development of the standard. The goal in this article is to highlight the benefits of and to promote the 3D 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 horizonal 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 3D 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 3D 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 3D 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 3D datum will occur incrementally. The transition needs to be supported by careful analysis and discussions of issues such as those listed in Part-I.

II. Particulars

A. 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 3D model for 3D data" obviates the need for low-distortion projections.

B. 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.

C. The overall topic of standards is quite large. This article focuses on a small, but important, segment addressing a 3D digital spatial data standard within the ECEF environment.

D. 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.

E. 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.

F. The GSDM involves little or no new science. What's new is beginning with the assumption of a single origin for 3D spatial data and building a spatial data model using existing rules of mathematics and logic. The "new" challenge is execution.

1. 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 3D "rocket booster catch" by SpaceX.

   a. Navigating
   b. Targeting
   c. Collision avoidance

   (The concepts of location, acceleration, motion, gravity, logic, and logistics are fundamental to understanding media reporting of military activities.)

2. 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. . .
   a. 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.
   b. A parallel circumstance applies for spatial data applications where the criterion centers on algorithmic integrity. Using a common 3D spatial data standard, embedded in AI apps, will help eliminate ambiguities such as. . .
      i.) What elevation is to be associated with a horizontal distance?
      ii.) Are reported (and archived) results based on true 3D or pseudo 3D?
      iii.) Is relative accuracy defined by an error ellipse or by standard deviation?

3. Computational efficiencies can be enhanced to the extent users exploit features of a common standard 3D spatial data model – for overview of example, see 3D diagram.
   a. Primary ECEF values (coordinates and covariances) – Box 1 of 3D diagram (For format example - see http://www.globalcogo.com/dbformat.html.)
      i.) ECEF values for location, X/Y/Z.
      ii.) Covariance values for designated point (optional).
      iii.) Correlation between points (optional).
   b. Geodetic latitude, longitude, and height are computed from X/Y/Z values.
   c. Point-to-point computations are based on coordinate differences.
   d. A rotation matrix is used to change a geocentric perspective to a local perspective.
      i.) Convention: a directed line segment is "there – here, point 2 – point 1, or forepoint – standpoint," e.g., $\Delta X = X_2 - X_1, \Delta Y = Y_2 - Y_1, \Delta Z = Z_2 - Z_1$.
      ii.) Changing between geocentric & local perspectives occurs at point 1 using bi-directional rotation matrices, see www.globalcogo.com/PG002.pdf.
      iii.) The resulting Δe, Δn, Δu components are identical to "flat-Earth" surveying.
   e. Point to point computations ("there" minus "here" or pt2 minus pt1) include:
      i.) 3D spatial distance in either geocentric or local perspective.
      ii.) Distance = $\sqrt{(\Delta X^2 + \Delta Y^2 + \Delta Z^2)} = \sqrt{(\Delta e^2 + \Delta n^2 + \Delta u^2)}$.
   f. Flat-Earth local horizontal distance, HD = $\sqrt{(\Delta e^2 + \Delta n^2)}$. Other HD options exist.
   g. The true 3D geodetic azimuth "here to there" (or Pt_1 to Pt_2) = atan(Δe/Δn).
   h. The back azimuth uses the same equation with Δe and Δn computed at forepoint.
   i. Difference in elevation is easily computed. . .
      i.) True 3D: difference in elevation = $h_2 - h_1$.
      ii.) Pseudo 3D: difference in elevation = Δu.

G. Philosophical considerations include:
    1. Efficiencies are realized by following and using a stated standard.
    2. Consequences involving waste/duplication can be avoided using a standard.
    3. Meta data are critical and should be included in the standard.
    4. Acknowledgement – sometimes, documenting what procedures were used may be more important than claiming compliance with a given standard.

H. By comparison, the claim is that the GSDM. . .
    1. Supports rigorous 3D spatial data computations for all disciplines worldwide.
    2. Enables a user to track the accuracy of data and to know "with respect to what?"
    3. Is less complicated than using traditional map projection procedures.
    4. Provides a better path from observations/measurements to useful solutions.
    5. Obviates the need for geoid modeling and low-distortion projections.
    6. Is sufficiently flexible to accommodate legacy spatial data components.\
    7. Gives the end user a tool for numerically filtering data from a database.
    8. Provides efficient methods for adding points to the 3D database. But note. . . (Optional covariance values for each point can define the quality of data added.)

I. 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:
    1. What is the height of this point with respect to other (nearby) points?
    2. What is the height of this point with respect to where it was previously?
    3. 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.)

J. 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."

K. With publication of the modernized NSRS, the elevation of all published 3D 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.

III. Examples – models and standards development

A. 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.

B. Gerard Mercator (1512 – 1594) never traveled far from home yet he created global maps.
    1. Mercator compiled and integrated information from many sources.

2. Mercator's crowning achievement was his World Map of 1569.
3. The spacing of parallels related to distortion became known as a conformal map.
    a. A conformal map can be used to sail a constant bearing across the ocean.
    b. 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.
4. Limitation – a map projection is strictly 2D. Modern spatial data applications are 3D.

C. Meridian surveys were used to compute the size and shape of the Earth.
    1. Early determinations presumed the Earth to be a sphere - Eratosthenes and others.
    2. Jean-Dominique (1625-1712), Director of Paris Observatory concluded Earth is prolate.
    3. Newton (1642-1727) argued that the Earth is oblate due gravity and centrifugal force.
    4. French Academy of Science sponsored meridian surveys to settle the dispute.
        a. 1636-1637 a 2-year survey in Lapland showed the Earth to be oblate, not prolate.
        b. 1635-1641 a 7-year expedition to Peru confirmed findings of the Lapland survey.

D. 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.
    1. Latitude at sea was easily estimated from the observed altitude of the sun (and stars).
    2. 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.
    3. Under pressure from the user community, Parliament passed the Longitude Act in 1714.
    4. The Act provided a prize for finding longitude at sea - ultimately won by a clockmaker.
    5. Harrison's first version, H1, was field tested in 1736 on a run to Libson, Spain.
    6. Although the test was largely successful, Harrison insisted on making improvements.
    7. It became a test of wills/methods - Harrison's clocks versus astronomical observations.
    8. The final version, H4, out-performed expectations and final payment was made in 1773.

E. 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 3D" vs "pseudo 3D," but there are parallels.)
    1. The solution included standardizing units of measure – length being one of them.
    2. The case was made that a length standard should be reproducible and globally applicable.
    3. A "better" survey of the Earth's quadrant was conducted between 1792 and 1799.
        a. The surveyed quadrant distance was set to equal 10,000,000 meters.
        b. A provisional meter bar was sent to the U.S.A. in 1794 and is preserved at NIST.
        c. A final was bar accepted in 1799, and copies were presented to foreign savants.
        d. Subsequent issues/discussions were settled at the "1875 Convention of the Meter" – see discussion posted by Wikipedia.

F. The Greenwich Meridian has served as the Prime Meridian (0° longitude) since 1884:
    1. "Greenwich Time," Derek Howse, 1980, Oxford University Press, Oxford, New York etc.
    2. 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."
    3. Of alternatives considered, Greenwich won based on shipping tonnage of users.
    4. Note: Spain agreed to vote for Greenwich if U.S. and Britian adopted the metric system.

G. Horizontal and vertical datums in the United States have served the end user for many years.
    1. Datums are defined and supported by the NGS – for a brief history see, U.S. Datums.

2. NAD 27, horizontal only, was defined in meters but accommodates the U.S. Survey Foot.
3. NAD 83, horizontal (2D/3D), also metric but accommodates the International Foot.
4. 2022 datum components – 4 horizontal datums and 1 vertical datum.
    a. NATRF2022, 3D horizontal datum, North American Terrestrial Reference Frame.
    b. PATRF2022, 3D horizontal datum, Pacific Terrestrial Reference Frame.
    c. MATRF2022, 3D horizontal datum, Mariana Terrestrial Reference Frame.
    d. CATRF2022, 3D horizontal datum, Caribbean Terrestrial Reference Frame.
    e. NAPGD2022, 1D datum, North American-Pacific Geopotential Datum of 2022.
5. The horizontal datums are 3D datums defined in terms of ECEF coordinates.
6. The geoid is the origin for the vertical datum instead of Earth's CM. Origins are disparate.

H. International Foot.
1. The meter has been the official standard of length in the U.S. since 1866.
2. The NGS has always worked in the meter but has supported "foot" units in practice.
3. After WWII the NATO countries collaborated on building military equipment.
4. Machining tolerances for aircraft engines created problems due to conversions:
    a. England: 1 inch = 2.539997 cm
    b. Canada: 1 inch = 2.540000 cm
    c. United States: 1 inch = 2.540005 cm
5. At the 1959 Conference on Weights & Measures, the United States and Great Britian, reached a compromise on the Canadian unit. The International Foot is 1 inch = 2.54 cm.
6. This and other policies give witness to the importance of having and using a standard.

I. Space X is reusing rocket boosters.
1. ChatGPT and Walter Isaacson in his book, "Elon Musk" both credit Elon Musk with:
    a. Going back to first principles and establishing a reason for an action.
    b. Discarding unproven methods/procedures.
2. An example of Musk's efforts (using 3D) can be seen at www.tru3d.xyz/catch.pdf.

J. A "common" data exchange point already exists for 3D spatial data – the GSDM.
1. Agreeing on a common point-format for data exchange will benefit many users.
2. From a GSDM database, each user is free to use other forms and formats.
    a. Meta data will be needed to specify terms of subordinate use.
    b. A bi-directional procedure will enable user data to be added to the database.
3. Features of the common exchange point are identified and given in:
    a. 3D Imaging of the Environment: Mapping & Monitoring, CRC Press 2024
        i.) Edited by John Meneely
        ii.) Covers results from various sensors brought to a common point.
        iii.) Data export/archival identified in Diagram 1.1, page 9.
        iv.) Summary of techniques listed in Table 1.2, page 11.
        (See illustration of solution www.tru3d.xyz/common.pdf.)
    b. Common exchange point serves both data generators and data users.
4. The 3D global spatial data model diagram – www.globalcogo.com/3D-diag.pdf.
    a. Stores ECEF coordinates in Box 1 – common to all users.
    b. Supports subsequent computations in 3D space & offers flexibility to user.
    c. GSDM includes a stochastic model for handling spatial data accuracy.
    d. GSDM has infinite life and serves all disciplines worldwide.

IV Forward Looking

A. A global standard for 3D spatial data will be beneficial to all users.
   1. It will fill the gap between X/Y/Z values, local (flat-Earth) use, and archived data.
   2. A spatial data model will accommodate both rigorous procedures and “simple” use.
   3. Spatial data accuracy feature (optionally) answers the question “with respect to what?”
   4. No distortion of map elements but gives answers based on assigned standard deviations.
   5. The quality of data drawn from a database is selectable by the user in choosing a filter.
   6. The quality of data added to a database needs to meet “standard input specifications.”
   7. The stochastic model accommodates standard deviations (variances) provided by a user.

B. Spatial data disciplines worldwide will enjoy benefits achieved by using a common standard.
   1. Governmental.
   2. Commercial.
   3. Professional.
   4. Technical.

C. Standards organizations that should embrace 3D global spatial data standard include – the following list was generated with the assistance of AI (ChatGPT).
   1. ISO.
   2. ASTM.
   3. FGDC.
   4. ASCE.
   5. ASPRS.
   6. Standards and Specifications for OPUS Projects - NOS NGS 92, October 2024.
   7. Others.

V. Summary of issues

A. A 3D datum is . . .
   1. Applicable worldwide.
   2. Mathematically superior.
   3. Logistically more efficient.
   4. Already defined and in place.
   5. Compatible with AI implementation.
   6. Already being used in innovative applications.

B. Historical practice utilizes separate horizontal and vertical datums.
   1. Impressive infrastructure and civil works projects are based on separate datums.
   2. Geoid modeling is required to reconcile geometrically disparate origins.
   3. The user community is heavily invested in established practices.
   4. Pseudo 3D and elevations are fundamental aspects of hydrologic modeling.
   5. Precedent carries enormous clout, but disruptive innovation will define future use.
   6. Innovative applications rely more and more on true 3D. The GSDM includes. . .
      a. Functional model – geometry and equations.
      b. Stochastic model – error propagation.
      c. Algorithmic integrity as essential in AI applications.

C. An ellipsoid makes a better reference for vertical than does the geoid because Earth's CM is. . .
    1. More stable.
    2. Easier to locate.

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

E. Water flows are driven by hydraulic grade.
    1. Grades can be closely approximated by differences in ellipsoid height.
    2. Corrections based on deflection-of-the-vertical are available if needed.
    3. Dynamic heights are used in critical cases over large areas.

F. Obstacles.
    1. Inertia of past practice – see AT&T link at the end of article.
    2. Negative elevations in Death Valley (below sea level) and at the coast.
    3. Numbers will change with publication of the modernized NSRS.
    4. Adopting 3D datum ellipsoid heights now will avoid confusion in the future.
    5. Unpopular as it may be, this is an excellent opportunity to "go metric." To that end, note that foot units can be used (along with other legacy units) in Box 10 of the 3D Diagram.
    6. People and attitudes can change. I may even purchase an electric car in the future.

G. Impact related to field procedures.
    1. Observations are independent while measurements may be correlated.
    2. Corrections for known physical circumstances are applied to eliminate systematic errors.
    3. Corrections used when "tying-in" (surveying) are applied in reverse in layout mode.
    4. The positional quality of a lay-out (staked position) is verified by tying it in (again).

Impact of 3D

A. Information contained in this document may not be taken seriously because. . .
    1. The current system works and is reliable.
    2. A credible case has not been made for making the transition to true 3D.
    3. Too much is invested in geoid modeling. It would be a shame to discard that investment.
    4. Many have proprietary interests in current practice and don't wish to change.
    5. The software needed for 3D practice is not yet conveniently (economically) available.
    6. Clients don't want it or need it. Disruptive innovation is the prerogative of others.
    7. Making the transition from pseudo 3D to true 3D would cost too much.
    8. The resources needed to "retrain" self, staff, associates, or clients are prohibitive.
    9. The claim is that orthometric heights are needed to determine which way water will run.
    10. The "will" to develop justification for transition to true 3D has yet to be developed.
    11. Current work is conducted using traditional practices, obviating the need to switch.

B. The information contained in this document **should be taken seriously**.

Will the 3D Genie ever return to the bottle?
see www.globalcogo.com/ATandT-Story.pdf

Building on Hazelton's Surveying Revolution Articles

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March 3, 2025

Hazelton's Part I and Part II:

Dr. N. W. J. Hazelton wrote several scholarly articles on The Surveying Revolution that were published in the Surveying & Land Information Science (SaLIS) Journal. Taken together, the articles present a comprehensive overview of surveying technology since about 1550 and describe the inevitable impact that "going digital" will have on the surveying profession (and society at large).

Hazelton, N.W.J., 2012, "The Surveying Revolution of 1550-1650: Implications for the Current Geospatial Revolution – Part I," Surveying & Land Information Science, (SaLIS), Vol. 72, No. 3.

Hazelton, N.W.J., 2024, "The Surveying Revolution of 1550-1650: Implications for the Current Geospatial Revolution – Part II," Surveying & Land Information Science, (SaLIS), Vol. 83, No. 2.

Examined in the larger historical context, Part I of Hazelton's visionary articles shows that the pattern of change in the surveying profession shares many of the characteristics of other historical revolutions and lays the foundation for many of the "disruptive innovations" described in his Part II.

Burkholder's Part I, Part II, and Part III:

Independent of and less scholarly than Hazelton's articles, the author wrote and posted several items (called Parts I, II, and III, http://www.tru3d.xyz 2024) that focus on "using a 3D model for 3D data." It seems that these developments serve to document the realization of Hazelton's vision.

Part I begins by listing factors and circumstances relevant to changes already realized and those forecast by Hazelton. Many challenges of "going digital" can be met by adopting the 3D global spatial data model (GSDM) which forms a rigorous concise bridge between the real physical world and its digital representation in a computer database (also called digital twins).

Part II – Benefits of a Standard, summarizes issues related to spatial data and lists particulars associated with the advent of the digital revolution. The discussion highlights examples of standards development and associated benefits. Part II closes by looking forward to the future, summarizing the issues, and acknowledging objections to implementing the GSDM. Finally, the question is, "Will the Genie ever return to the bottle?"

Part III, still in draft form, is planned to have four sections – sections 1 and 2 will focus on characteristics of Process and Content. Section 3 will discuss the importance of transparency while Section 4 will look at geometrical integrity. Section 4 is particularly important when anticipating the use of artificial intelligence (AI) in the context of spatial data applications

Chronology of author's involvement:

1. The author studied Dr. Hazelton's articles carefully and found many reasons to support the points he made. Hazelton's resource materials are extensive and are used effectively to explain "how we got to where we are" with regards to the use of digital spatial data.

2. The conceptual foundation for ideas espoused by the author was laid in the 1970s by Professor Ralph Moore Berry at the University of Michigan – there is no substitute for building on proven fundamentals. Berry (at Michigan) and, later, McEntyre (at Purdue) both indulged in abstraction when discussing surveying and land data systems in professional practice.

3. After graduating from Michigan, responsibilities at Commonwealth Associates, Inc., Jackon, Michigan, included performing mapping and engineering layout computations on a high-voltage transmission line project for the Detroit Eidson Company. Computations were based on the elevated Michigan Coordinate System as designed by Professor Berry. That procedure worked as intended and was used by various disciplines involved in the project. But surveyors, vendors, and others often mis-used it. See the abstract http://www.globalcogo.com/MichGSF80.pdf.

4. Professional activities within ASCE over the past 50 years, in professional practice, research, and teaching come under the umbrella of the convergence of abstraction/technology/policy/practice – see Part I. Implementation of "a 3D model for 3D data" grew out of that thought process.

5. It would be a mistake not to acknowledge the value of the 1990/91 sabbatical at the University of Maine. Dr. Leick (and others) shared their knowledge and provided lots of inspiration. "Using GPS Results in True Coordinate System" grew out of that experience – see True 3D versus Pseudo 3D.

6. Facing the datum transition, NAD 27 to NAD83, Dr. Kurt Bauer, Executive Director of the SE Wisconsin Regional Planning Commission (SEWRPC), wanted to develop reliable datum transformation procedures for the SEWRPC area. The concept of using an integrated 3D datum in place of separate horizontal and vertical datums was presented. It was a short discussion. Although Dr. Bauer listened carefully, he was not swayed. Two separate transformation projects were completed – one for horizontal and one for vertical. However, acknowledging the possible benefits of a 3D system, SEWRPC commissioned a study to incorporate horizontal and vertical spatial data into one system – see Definition of 3D model. Dr. Bauer retired at the end of 1996. The 3D report, published in January 1997, was shelved and "forgotten."

7. The formal definition of the Global Spatial Data Model (GSDM) includes both functional and stochastic models for spatial data and was filed with the U.S. Copyright Office in 1997.

    a. All equations and procedures included in the GSDM are in the public domain.
    b. The GSDM uses a single origin for 3D data. Computations are performed in 3D space.
    c. Local accuracy procedures defined by the stochastic model portion of the GSDM have been challenged in technical literature – but, to date, successfully defended.

8. The first Edition of the book, "The 3D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure," was published by CRC Press in 2008. The 2nd Editon, "The 3D Global Spatial Data Model: Principles and Applications," was released in July 2017 (copyright 2018). Although the original subtitle remains valid, CRC Press marketing insisted on the change.

9. Although the GSDM includes concise procedures for spatial data computations worldwide, the user community has been reluctant to embrace a unifying spatial data model for many reasons. However**, Dr. Hazelton's comprehensive review of the Surveying Revolution and its impacts on modern practice provides context and justification for implementing the GSDM.**

10. Resources developed/provided by N.W.J. Hazelton:

    a. The Surveying Revolution of 1550-1650: Implications for the Current Geospatial Revolution – Part I. "The pattern of change, examined in the larger historical context, shows that the revolution of 1550-1650 has the same characteristics of many historical revolutions . . ." Many advancements in technology and methodologies are described and Hazelton notes that "major historical changes cannot be undone."

    b. The Surveying Revolution of 1550-1650: Implications for the Current Geospatial Revolution – Part II. This article attempts "to find parallels between that [historical] revolution and the current geospatial revolution that started about 1950." Those issues resonate well with many who have enjoyed a front-row seat to those changes.

    c. In email correspondence with author: Dr. Hazelton makes the following points:
        - Peter Medawar (1960 Noble Laureate in Medicine and Physiology) notes that as a science matures there are over-arching concepts that greatly simplify the subject.
        - Vectors, as defined by coordinate differences, provide a direct connection to the measurements used to compute a control network. Storing those measurement vectors supports re-computation of a network if/when needed.
        - Dr. Hazelton does not make this point, but vectors also facilitate efficient computation of directions/distances in 3D space when using the GSDM.

11. Resources referenced or developed by Earl F. Burkholder include:

    a. Structure of Scientific Revolutions, 3rd Ed. 1996, Thomas Kuhn. This book is highly regarded in scientific circles and describes many features associated with advancing knowledge, practices, and technology. It is a bit cynical to acknowledge that the process of adopting new technology is to wait until current leaders are retired. Although coming from different perspectives, Drs. Kuhn and Hazelton cover many of the same points.

    b. 3D Spatial Data – Time is 4th Dimension, Part I The purpose of this item is to list many of the "givens" associated with development of current systems being used. It also steps back and looks at "big picture" characteristics of spatial data before showing how the GSDM fulfills the requirements of a modern digital model for spatial data.

    c. Benefits of a Standard, Part II Disruptive Innovation is a consequence of the digital revolution and challenges many to look at new/better ways of achieving a goal. In keeping with the observation made by Peter Medawar (section 10.c this paper) the over-arching concept of the GSDM provides better tools for the spatial data user. After discussing particulars and benefits of adopting the GSDM, Part II includes examples (e.g., finding longitude at sea and adopting a standard meter or length) of the development of models and the benefits of standardization. Part II ends with a summary of issues in the context of forward-looking consequences of the impact of adopting the GSDM.

    d. Part III is a draft of "Challenges and Opportunities – Going Forward. This paper is only in the beginning stages of completion. The first section will look at how different perspectives of process and content contribute to future policies/practice. Some users are more adept at (focus on) content while others are more concerned with advancing user (administrative) accomplishments. In either case, a subsequent section will emphasize transparency of algorithms (suggestions are welcome) and the final section will highlight the importance of integrity. The book "Unmasking AI" by Joy Buolamwini provides a dramatic example of algorithmic justice (having to do with facial recognition) while algorithmic integrity is critical in spatial data applications. Maybe the best example for spatial data users is the difference between "true 3D" and "pseudo 3D." Being transparent is essential and integrity suffers if/when concepts are mixed inappropriately.

e. "3D Imaging of the Environment: Mapping and Monitoring," Edited by John Meneely, 2024, provides a valuable service to the spatial data community by identifying (among others) a "common data exchange point" that can be shared alike by generators and users of spatial data. Regardless of how spatial data are generated the GSDM provides a logical "handoff" point for archiving the data and/or as the basis for subsequent spatial data applications. Diagram 1.1 and Table 1.2 summarize those concepts.

f. M. Govorcin, D. Bekaert, B. Hamlingtoin, S. Sangha, and W. Sweet, "Variable vertical land motion and its impact on sea level rise projections," Science Advances 11, eads8163 (2025), 29 January 2025. https://www.science.org/doi/10.1126/sciadv.ads8163. This article is relevant and important because:

- It is an example of a similar effort (study) needed to document issues, practices, consequences, and the economic impact of using true 3D compared to pseudo 3D, see http://www.globalcogo.com/3D-Development.pdf.
- Their results are reported in terms of relative vertical differences. Thus, the article avoids the question of referencing vertical motion to the geoid or the ellipsoid.
- It is authored by high-level professionals employed by the Jet Propulsion Laboratory, California Institute of Technology and National Oceanic Atmospheric Administration.
- Subsequent policy decisions related to sea level rise will be based on "solid science."

12. The preceding material is summarized as part of a Vision (path forward) for implementation of the GSDM. Issues that need to be addressed include:

a. The Earth's center of mass is more stable and is easier to locate than the geoid.
b. The importance of hydraulic gradients in the real world is undisputable. A high-level study needs to discuss "best" methods for computing gradients. The impact of gravity is huge!
c. The Scientific Method as discussed in Chapter 1, "Data Analysis Techniques for Physical Scientists," Claude Pruneau, Cambridge University Press describes credible procedures. The proposed study needs to conform to the principles outlined in said Chapter 1.
d. As described in Chapter 1, "Normal" science uses models in computations. Corrections are applied to physical measurements to facilitate "working on the same page." Two examples are equation of time and polar motion. Pruneau cites Kuhn frequently.
e. The costs and procedures for making the transition to using ellipsoid height for the third dimension need to be identified and the "way forward" needs to be planned carefully.

Many disciplines and organizations use digital spatial data and deserve a voice in future use. Some may justifiably choose to "go it alone" (the military, for example) but the advantages of commonality should ultimately prevail for spatial data users worldwide. What organization should be tasked with conducting such a study? This author suggested previously that NIST should conduct such a study. Might another option be more appropriate?

Facilitating Exchange Between Spatial Data Generators and Users

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April 29, 2025

The digital revolution continues to drive development of sensors for generating spatial data and has spawned innumerable spatial data applications worldwide. Spatial data careers captivate the interests and talents of technicians, professionals, researchers, and entrepreneurs alike. Additionally, many managers, administrators, and support personnel enjoy participation in the spatial data arena.

The overall scope of spatial data activities is huge to the point of being overwhelming. That challenge can be mitigated by recognizing a division of focus (and talents needed) between generating spatial data (science and measurement) and using spatial data in myriad applications (characterized by GIS). Notwithstanding a difference of focus, the geometry of spatial data is common to both camps and the 3D global spatial data model (GSDM) provides a modern-day Rosetta Stone for bridging the gap between those activities devoted to generating spatial data and those using spatial data.

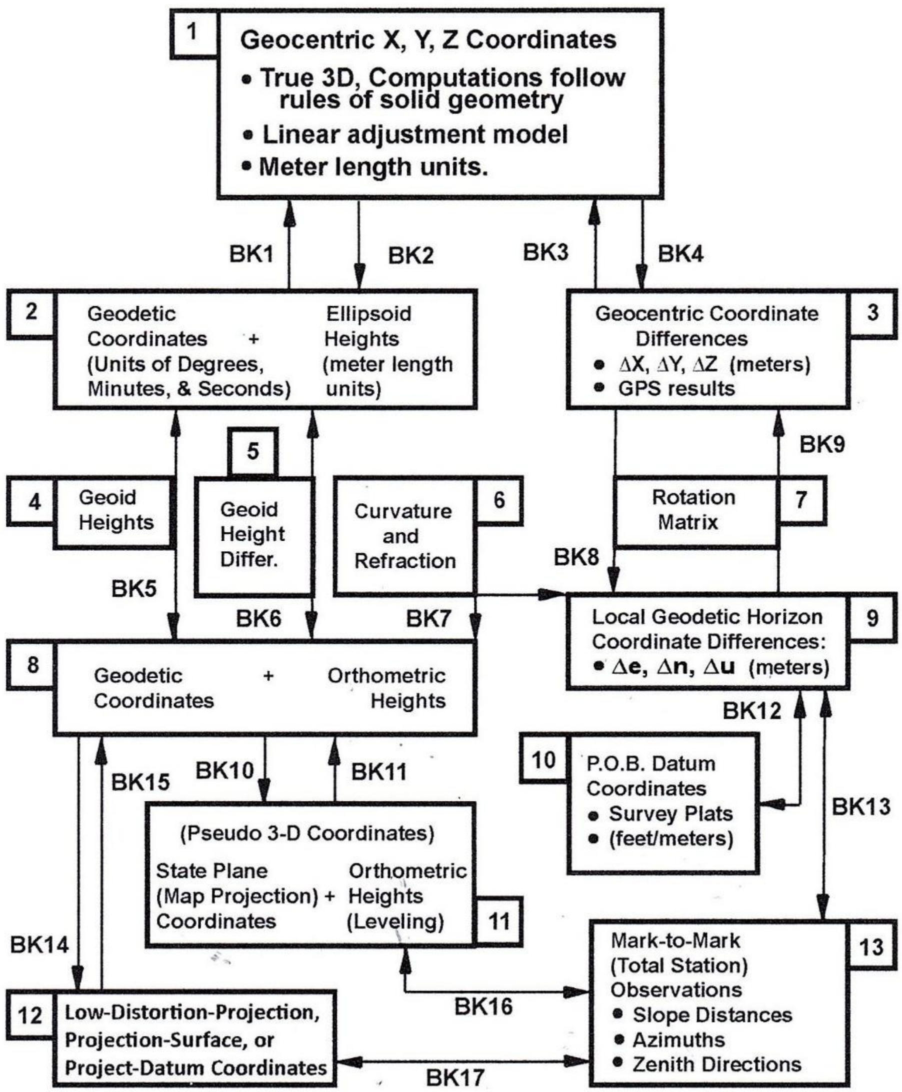
Bill Hazelton is a visionary who has written a comprehensive summary of the spatial data revolution and puts many issues into perspective. In private correspondence Dr. Hazelton highlighted the view of Nobel Laureate Peter Medawar (see comments on page 3) who noted that as science matures, overarching concepts serve to simplify complex issues. Such is the case with the GSDM, a common rigorous spatial data model, which serves both camps. That area of common interest can be inferred from Diagram 1.1 and Table 1.2 of "3D Imaging of the Environment: Mapping and Monitoring," Edited by john Meneely, CRC Press 2024.

Diagram 1.1 includes a schematic of activities associated with generating spatial data. Various activities are grouped under the following categories – Planning & Advanced Work, Control Survey, Primary Spatial & Image Data Capture, and Data Processing. Regardless of the technology involved, those measurement processes culminate in determination of Earth-centered Earth-fixed (ECEF) coordinates which are then "handed off" to Data Export and/or Archival. Data dissemination is divided into Public and Professional categories. The point is that all spatial data users benefit from sharing a common geometrical heritage. A 3D database is the primary storage for ECEF data and the GSDM provides a simple reliable exchange format for the Export/Archival portion of the diagram.

Table 1.2 summarizes the scales (>km, <km, <cm), specific techniques (LiDAR, scanning, photogrammetry, total station, GNSS, etc.), illustrative accuracies (30 cm down to 0.1-0.2 mm), and output data types (primarily X/Y/Z & RGB). Spatial data location is uniquely defined by X/Y/Z. Given the convergence of abstraction/technology/policy/practice, the case is made that the GSDM is an appropriate standard for spatial data exchange and usage worldwide – see Part I and Part II.

In addition to supporting the features and benefits described in Diagram 1.1 and Table 1.2, the GSDM accommodates all levels of spatial data accuracy by allowing the user to track errors in the measurement process, to store the stochastic information in the 3D database, and to determine the uncertainty of any quantity computed from the stored elements. That means there are no restrictions on the quality of data stored (so long as appropriate error estimates are included in the measurements) and that the quality of data retrieved from the data base can be screened with a user-selected numeric filter – see http://www.globalcogo.com/accuracy.pdf.

The 3-D Global Spatial Data Model Diagram



2-D Horizontal + 1-D Vertical or True 3-D Spatial Data