3-D Digital Geospatial Data Introduce a New Ball Game:
Disruptive Innovation, Back to Basics, and Expanding Opportunities

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Abstract

Geospatial data are characterized as digital and 3-D. This article advocates using a 3-D model for geospatial data**.** Years ago, the U.S. Department of Defense adopted the Earth-centered Earth-fixed (ECEF) rectangular coordinate system for computing satellite orbits. Rules of solid geometry are applicable worldwide in the ECEF system. Historically, surveying and mapping practice incorporated flat-Earth assumptions and included separate horizontal and vertical datums. The Earth is not flat. Geometrical integrity is preserved in higher level applications by using an ellipsoid model for position computations. Latitude/longitude express horizontal position and elevation (or geodetic height) describes vertical. While that 3-D model is used successfully, drawbacks include disparate units (curvilinear and length), complexities of computing on the ellipsoid, separate origins for elevation and height, and locating the geoid. The 3-D global spatial data model (GSDM) is built on the ECEF system, computations are performed in 3-D space, and the "up" dimension is referenced to Earth's center of mass. Benefits of using the GSDM include compatibility with artificial intelligence and machine learning (AI/ML). With the GSDM, the need for geoid modeling is dramatically reduced and map projection distortions can be avoided. Transition to future practice will be influenced by the convergence of "abstraction/technology/policy/practice."

Introduction

Given: Citizens of plant Earth enjoy many benefits derived from use of spatial/geospatial data.

Assertion: Spatial data can be manipulated more efficiently, and society can be better served, if a 3-D model is used for 3-D geospatial data. The 3-D global spatial data model (GSDM) is concisely defined, is applicable worldwide, and exploits characteristics of 3-D geospatial data.[1]

"Disruptive Innovation" describes one consequence of the digital revolution. Philosophical discussions compare consequences of "doing things right" versus "doing the right thing." Some promote "change for the sake of change" while others justifiably contend "if it isn't broken, don't fix it." As demonstrated in the technical literature and in practice, surveying and engineering professionals enjoy enviable stature worldwide and have a reputation of doing things correctly. The premise of this article is that, to maintain relevance in a changing world, the surveying and engineering professions need to stay abreast of changes fostered by the digital revolution and incorporate those changes consistent with underlying professional and ethical principles. Doing things right justifiably receives much attention. On the other hand, this article visits the broader question, "What is the right thing?" And is doing the right thing for the wrong reason a justifiable alternative? Implementing the GSDM includes doing the right thing for the right reason.

Circumstance

A. Geospatial data define where things are.
B. With advent of the digital revolution, geospatial data are primarily digital and 3-D.
C. Scientists, mathematicians, and geodesists define the spatial data infrastructure worldwide.
D. Geomatics professionals adopt policies/procedures for using the spatial data infrastructure.
E. Spatial data applications impact the entire spectrum of talent – technician to researcher.
F. Significant benefits can be realized by using a common 3-D model for 3-D geospatial data.
G. Spatial data accuracy is increasingly critical in management, planning, and decision making.
H. The 3-D global spatial data model (GSDM) can be applied to past/present/future practices.

Overview – looking back

A. Generic spatial data applications typically include flat-Earth limitations – gravity is ignored.
B. Geospatial data are referenced to the Earth and, due to gravity, the Earth is nearly spherical.
    1. Geodetic latitude/longitude/height use mixed units, ellipsoid is model for computations.
    2. Using Earth-centered Earth-fixed (ECEF) coordinates, computations are in 3-D space.
C. Map projections define a 2-D connection between latitude/longitude and plane coordinates.
D. Elevation, the third dimension, is referenced to the geoid. Impact of gravity is significant.
E. Horizontal and vertical datums have separate origins. True 3-D integrity may be compromised:
    1. Horizontal datum references 2-D positions – plane coordinates or latitude/longitude.
    2. Vertical datum references 1-D elevation to sea level (intuitive) or the geoid (scientific).
    3. Geoid modeling (gravity dependent) is needed to reconcile disparate origins.[2]
F. Modernization of National Spatial Reference System (NSRS) will replace NAD 83 and NAVD 88.

Overview – present

A. The digital revolution drives many changes in the use and applications of geospatial data.
B. Levels of abstraction in the use of 3-D digital geospatial data continue to evolve.
C. Characteristics of 3-D digital geospatial data foster various disruptive innovations.
D. Electronic devices supplement (extend) human capacity. The role of a model is critical.
E. Humans are resilient and adapt to change – witness changes in last 50, 20, 10, or 5 years.
F. On the other hand, old habits die hard – "if it isn't broken, don't fix it."
G. Both perspectives are described by Thomas Kuhn[3], "The Structure of Scientific Revolutions."

Overview – looking ahead

A. Innovation (often disruptive) can lead to greater efficiencies in many human endeavors.
B. Adhering to rules of math/science/engineering is essential when defining a model.
C. "Simple" and "adequate" can be mutually exclusive when evaluating the role of a model.
D. Engineering/surveying practice builds on the foundation of the spatial data infrastructure.
E. GISs create enormous benefit by adding metadata to the geometry of geospatial data.
F. "Measure once, use twice" and process automation enhance economic benefits for all users.
G. Reliable spatial data accuracy is critical for automated navigation and driverless anything.
H. **Integrated 3-D model is essential for artificial intelligence and machine learning (AI/ML).**
I. Challenge for spatial data (geomatics) professionals is to become familiar with disruptions created by the digital revolution and to deliver high-quality professional results to all clients.

Build on basics to incorporate new technology

A. Geometrical elements include points, lines, angles, surfaces, and volumes.
B. Spatial data are primitive and fundamental. Rules of solid geometry govern data manipulation.
C. Geospatial data types include coordinates and differences.[4] Angles and volumes are derived.
D. Forms of spatial data – raster data are defined in terms of coordinate differences (vector data).
E. Basics processes include manipulation of measurements/observations and error propagation.
F. Functional model equations include geometry to define location.
G. Stochastic processes include uncertainty, error propagation, least squares, residuals, thresholds.
H. Mathematical definition of "spatial data accuracy" provides foundation for common usage.[5,6]
I. Management practices related to geospatial data are expanded to include AI/ML.

Evolution of spatial data abstraction

A. Concepts are related to convergence of abstraction/technology/policy/practice.
    1. Surveying/engineering focus on geometrical models (spatial/geospatial data).
    2. GISs add "layers" for organizing information – abstraction includes use of metadata.
    3. Automation and workflow optimization – abstraction includes management of data.
    4. Artificial intelligence and machine learning – processes bypass human intervention.
B. Importance of integrity increases with each level of abstraction.
    1. Importance measured, in part, by consequences of failure.
    2. Spatial data accuracy quoted in terms of standard deviations, but with respect to what?
    3. Confidence levels and hypotheses testing are applied to predetermined thresholds.
    4. Metadata are important. Standard deviations (must be reliable) provide a numeric filter.
    5. Error propagation used to determine quality (sigma) of any derived geometrical element.
    6. User-specified thresholds (filters) are imposed for efficient discrimination of useful data.

Huge challenge

A. Two competing camps have evolved with each needing "dominance" in their practice area.
    1. 2-D/1-D – Long established practice of using separate horizontal and vertical datums.
    2. 3-D – Automation requires true 3-D built on an integrated datum for geospatial data.
B. Impasse is legitimate and economic consequences are significant!
    1. 2-D/1-D mapping practices are used worldwide. Can transition to 3-D be justified?
    2. Automation requires unambiguous geometry and unquestioned integrity (accuracy).
    3. 3-D standards need to be studied, adopted, and enforced (especially in critical areas).

Ambitious Proposal – use of a common 3-D Model is indispensable.

A. Adopt the 3-D global spatial data model (GSDM) which serves spatial data users worldwide.
    1. Functional model defines location with well-known equations of solid geometry.
    2. Stochastic model provides procedures for error propagation and tracking.
       (see www.globalcogo.com/role.html.)
C. Two important consequences for modernization of NSRS in the United States are:
    1. Using geodetic height for the third dimension obviates need for most geoid modeling.
       (see www.globalcogo.com/ImpactOfGravity.pdf.)
    2. Low-distortion projections aren't needed if engineering/surveying/GIS use the GSDM.

(see www.globalcogo.com/simple.pdf.)

D. GSDM is global, "simple," already in place, and all equations are in the public domain.
E. Some already use the ECEF coordinate system as a reference. GSDM gives it a name.
F. GSDM bridges gap between physical world and digital representation – known as Digital Twin.

Economic Impact – opportunities can be enhanced through collaboration and using the GSDM.

A. Artha Report quantifies value of spatial/geospatial data in India – has global implications.
   https://geospatialworld.net/consulting/reports/geospatial-artha-report-2021.html
B. UN Report describes "The Power of Where" as the 4th Industrial Revolution
   https://www.geospatialworld.net/gw-assets/pdf/GKI-White-Paper.pdf
C. The GSDM can be instrumental in meeting the "BIG DATA" challenge issued by NOAA
   http://www.globalcogo.com/BIGDATA.pdf (from 2014 - some details are obsolete.)
D. FGDC Strategic Plan
   https://www.fgdc.gov/nsdi-plan/nsdi-strategic-plan-2021-2024.pd
E. Infrastructure Investment and Jobs Act includes impact of spatial data as a component
   https://en.wikipedia.org/wiki/Infrastructure_Investment_and_Jobs_Act#:~:text=The%20Infrastructure%20Investment%20and%20Jobs%20Act%20%28IIJA%29%2C%20commonly,by%20President%20Joe%20Biden%20on%20November%2015%2C%202021.
F. COGO Infrastructure Report Cards (data for next Report Card are being assembled)
   2015 https://www.fgdc.gov/ngac/meetings/march-2015/cogo-nsdi-report-card-ngac-march-2015.pdf
   2019 https://img1.wsimg.com/blobby/go/d03ac9fe-b503-4c13-983d-a7dbdff5c7fd/downloads/2018COGOReportCard.pdf?ver=1590594376430
G. WGIC – Launch of WGIC Spatial Digital Twins Report, April 5, 2022
   https://www.assetmapping.events/spatial-digital-twins
H. NGS – Modernization of National Spatial Reference System (NSRS)
   https://geodesy.noaa.gov/datums/newdatums/index.shtml
I. Smart Cities Initiative – needs to employ a common spatial data framework for all disciplines
   https://smartcities.at/en/
J. Singapore Creates Digital Twin
   https://venturebeat.com/2022/02/23/how-singapore-created-the-first-country-scale-digital-twin/?utm_medium=email&utm_source=rasa_io
K. GIM International – prints many articles on advances in geospatial applications
   https://www.gim-international.com/magazine

Geomatics professionals in many disciplines participate in various functions while using geospatial data.

A. Organizational mission – what is impact of spatial/geospatial data on institutional mission?
B. Policies – scientists, professionals, and politicians(?) develop policies carries out by managers.
C. Standards - developed by consensus of experts from various disciplines worldwide.
D. Education – needed at all levels, technician to researcher, focus of inquiry can be narrow/broad.
E. Accreditation – provides assurance of "minimum rigor." Fox guarding chicken coop may be issue.
F. Registration – serves to protect safety and welfare of public. Varies by jurisdiction.
G. Continuing education – those opportunities providing only "lip service" need to be updated.
H. Vendors – (both hardware/software) have a huge responsibility beyond being profitable.

Documents related to "The 3-D Global Spatial Data Model (GSDM):"

A. Definition and description of a global spatial data model (1997)
   http://www.globalcogo.com/gsdmdefn.pdf
B. The digital revolution begats the global spatial data model (GSDM) (2003)
   http://www.globalcogo.com/gsdm-eos.pdf
C. Viewing spatial data from the 3-D perspective (first place Award) (2004)
   http://www.globalcogo.com/setepaper.pdf
D. Spatial data accuracy as defined by the GSDM (1999)
   http://www.globalcogo.com/accuracy.pdf
E. Evolution of meaning for terms – network accuracy and local accuracy (2016)
   http://www.globalcogo.com/appendixE.pdf
F. AGU poster summary of transition to 3-D (2016)
   http://www.globalcogo.com/poster.pdf
G. Concepts of Spatial Data Accuracy Need Our Attention (2017)
   http://www.globalcogo.com/EFB-SaGES-ALTA-NSPS.pdf
H. The Global Spatial Data Model (GSDM) Preserves the Geometrical Integrity of a Geospatial Digital Twin
   http://www.globalcogo.com/GSDM-and-DT.pdf (2022)

Books describing the GSDM published by CRC Press

A. The 3-D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure 2008
B. The 3-D Global Spatial Data Model: Principles and Applications, 2nd Ed. 2018

Conclusions – Overview and Road Ahead

A. Engineering/Surveying (Geomatics) are able to make huge contribution.
B. Geomatics professionals have vested interest in future of profession.
C. Standards need to be discussed and developed.
D. Education/licensure need to be re-evaluated in terms of role of abstraction.
E. Implementation should go forward in a collaborative manner.
F. The creative input of many individuals will assure positive impact.
G. Robert F. Kennedy – Some men see things as they are and ask, 'why.' I dream of things that never were and ask, 'why not.'

References

[1] Burkholder, E.F., 1997, "Definition and Description of a Global Spatial Data Model," filed with the U.S. Copyright Office, Washington, D.C., www.globalcogo.com/gsdmdefn.pdf.

[2] Burkholder, E.F., 2021, “Reconciling Gravity and the Geometry of 3-D Digital Geospatial Data,” filed with the U.S. Copyright Office, Washington, D.C., www.globalcogo.com/ImpactOfGravity.pdf.

[3] Kuhn, Thomas, 1976, *Structure of a Scientific Revolution,* University of Chicago Press

[4] Burkholder, E.F., 2018, *The 3-D Global Spatial Data Model, 2nd Edition*, CRC Press, Coca Raton.
While two forms of spatial data may be encountered in Digital Twins (vector and raster), seven types of spatial data are listed in Chapter 3.

[5] Burkholder, E.F., 1999, “Spatial Data Accuracy as Defined by the GSDM,” Journal of Surveying and Land Information Systems, Vol. 59, No. 1, www.globalcogo.com/accuracy.pdf.

[6] Burkholder, E.F., “Discussion of ‘Rigorous Estimation of Local Accuracies Revisited’ by Tomás Soler and Jen-Yu Han,” Journal of Surveying Engineering, Vol. 145, No. 2.
Note: ASCE posted this Discussion as a free download for about 2 years – 880 downloads are documented on the ASCE website as of March 2022. ASCE now charges for downloads.
www.globalcogo.com/validation.pdf.