In Support of an Ambitious Proposal – Using a 3-D model for 3-D geospatial data

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Purpose: This ambitious proposal promotes development and adoption of geometrical standards for geospatial/spatial data worldwide (terms have been used interchangeably).

Premise: **A 3-D model should be used for 3-D geospatial data.**

Agency: **A universal 3-D spatial data model can provide enormous benefits to spatial data users. What organization might be best suited to "formalize" such a standard?**

Solution: A proposed 3-D model has been formally defined – see "Definition and Description of a Global Spatial Data Model (GSDM)," www.globalcogo.com/gsdmdefn.pdf.

Overview: The digital revolution drives convergence of abstraction/technology/policy/practice. Adapting to "disruptive innovation" is more of a challenge for some than others.

Obstacle: Due to extensive investment in traditional models and processes, any proposal to adopt a "better" model is viewed with skepticism - "if it ain't broke, don't fix it." **It's broken!**

Observation 1: Overcoming the obstacles may be more of a political challenge than a technical one.

Observation 2: The GSDM is rigorous and simple. For many spatial data users, it obviates the need for more sophisticated tools such as geoid modeling and low-distortion projections (LDPs).

Summary:

- Surveying, mapping, and other disciplines make extensive use of spatial/geospatial data.
- Existing models for spatial/geospatial data rely on separate horizontal and vertical datums.
- Due to gravity, elevation is referenced to sea level (geoid), an origin not shared with horizontal.
- The digital revolution is a driving force for use of 3-D digital spatial/geospatial data – globally.
- A digital twin (DT) for geospatial data connects the physical world with an electronic database.
- Geometrical integrity can suffer when using separate horizontal/vertical datums, i.e., pseudo 3-D.
- The Earth-centered Earth-fixed (ECEF) system has a single origin and preserves true 3-D integrity. (See comparison of true 3-D and pseudo 3-D, www.globalcogo.com/true-versus-pseudo.html.)
- Models: the speed of light, duration of a second, and length of a meter are "fixed" – spatial data?
- The Earth's center of mass is more stable ("fixed") and easier to locate than is the geoid.
- Standards/definitions for spatial data accuracy vary according to discipline and application.
- An important issue which should be clear in all cases is, "accuracy with respect to what?"

Related issues:

Many issues are related to use of geospatial data. Several are discussed here but subsequent versions of this document will contain addition discussion and details.

- Convergence of abstraction/technology/policy/practice:

  The digital revolution drives innovation in many areas – in this case spatial data on a global scale. The convergence of abstraction/technology/policy/practice impacts many walks of life because geospatial data are the underlying foundation of many human activities. Simple geometry is integral to the spatial data infrastructure on a global scale and deserves rigorous re-evaluation. Rules of solid geometry were formalized by Descartes in 1637 and are directly applicable in the ECEF coordinate system. Many learn plane Euclidean geometry in high school and routinely use maps/diagrams to visualize spatial relationships. The third dimension is accommodated in an ad-hoc manner by adding "z" to the x/y system of plane coordinates. That works well for spatial data in a flat-Earth environment. But the world is not flat and spatial data referenced to the curved Earth are called geospatial data. When pushing the limits of flat-Earth assumptions, gravity – one of the fundamental physical forces – cannot be ignored if geometrical integrity is to be preserved. This is where the role of a model becomes critical. Disruptive innovation means that comfortable habits and ways of doing things are replaced by "new" procedures that are more efficient and that accommodate a greater range of activity. Disruptive innovation does not mean that prior results are inherently "inferior." But, in the context of spatial/geospatial data, the GSDM model is less complicated, is easier to use, and acknowledges the difference between spatial and geospatial data. Although transition, pseudo 3-D to true 3-D may take time, benefits realized from standardization will ultimately justify the effort.

  The focus here is on geometrical geodesy but that is only part of the larger discipline. Historically, the mathematical ellipsoid has been the standard reference for geodetic computations. Traversing and computing inverses on the geodetic line are rather complex but algorithms have been developed and programmed which makes reliable solutions available at the "touch of a button." Alternatively, map projections have been developed to "simplify" computations for those who prefer using plane Euclidean geometry for mapping and navigation. Admittedly, computations on a mapping grid were simplified but algorithms for the many projections available can be quite complex (i.e., conformal projection from ellipsoid to sphere to plane). Here again, software comes to the rescue. One "tricky" challenge is to make sure that the software being used matches the problem to be solved. By comparison, computations using the GSDM are performed in 3-D space and no such approximations are needed. The GSDM equations are much less complicated and geometrical integrity is governed by the quality of the measurements, not the model.

  The fact remains – physical measurements made with plumbline-based instruments (transits, theodolites, levels, range poles, and inertial gyroscopic instruments) are affected by gravity. Corrections need to be applied to those physical measurements before the data are compatible with computations in the true 3-D environment. Incidentally, except for very small corrections for deflection-of-the-vertical over the length of the range pole, GNSS derived vectors and positions are already compatible with the true 3-D environment. Additional study is needed to document the magnitude of and need for such corrections to remotely sensed data (lidar, IMUs, laser scans, and photogrammetry). Many of those corrections are already routine for practicing professionals.

- The Marketplace:

  Manufacturers excel at developing and marketing new technology to consumers. That will not change - consumerism drives the global economy. Without being critical of existing business practices, perhaps a lesson can be learned from Steve Jobs. As the creative genius at Apple, Jobs promoted the idea of developing “must have” technology and creating demand for something the consumer did not know they wanted. What might it take to convince surveyors, engineers, GIS practitioners, and other spatial data users to adopt a common “no distortion” system (true 3-D) having no zones but, with one set of solid geometry equations that can be applied equally at any and all levels – local, state, regional, national, and even global (including the pun for elevation)?

  Significant additional information could (and should) be added to this marketplace category.

- Models:

  The role of a model is often taken for granted because details of existing models are so firmly entrenched in the way things have been done in the past. In the case of digital geospatial data, the concepts of horizontal and vertical are ingrained in human psyche because of the way humans walk erect of a “flat” Earth. Maps show the 2-D location of specified features. Tracking the flow of water on the Earth directly supports the way humans think about elevation. Sea level is a well-known reference for elevation and is obvious to everyone – even for those who have never been to the coast. It takes effort to re-think referencing vertical to Earth’s center of mass.

  Selection of a model often involves a trade-off between simplicity and rigor. The preferred model is one that is simultaneously adequate and simple – see. . .

  http://www.globalcogo.com/role.html

  Sophisticated (interrelated) models have been adopted for the speed of light, the number of atomic oscillations in a second, and the length of the meter. Is it conceivable that the exact value adopted for the speed of light will change in the foreseeable future? Probably not. The point here is that true 3-D is preferred to pseudo 3-D because the Earth’s center of mass (reference/origin) is more stable and easier to locate than is the geoid.

  Complex models relating time, gravity, and the geoid are discussed in several references.[1, 2, 3] In reading those references, it seems that <u>relative</u> geoid heights will be realized in the future using precise time. But isn’t it true, for spatial data users, that the <u>absolute</u> distance (geoid height) between the geoid and the ellipsoid at a point is more critical than determining <u>relative</u> geoid height between points. Isn’t it also true that determining “the direction water will run” is more closely related to the slope of the geoid (deflection-of-the-vertical) than to the distance between the geoid and the ellipsoid? Silly question – if the equation-of-time were readily available to everyone, would that mean everyone should arrange their schedules according to true solar time as opposed to mean solar time? Geoid heights and equation-of-time are both critical and available to those needing them. The bi-directional nature of corrections defined by a model should be exploited for the benefit of the end user.

- Geographic information systems (GISs):

  Geographic information systems (GISs) have become indispensable for taking advantage of new technology when working with digital spatial data. Using a GIS, many users are more productive, able to work more efficiently, and make better decision. Software providers develop and market those features identified and requested by the consumer. It is a self-feeding cycle. . . based on a preconceived idea of an analog model. What will happen if and when the consumer asks for better tools? They will be developed and sold to those asking for same. Observation - there really is nothing new here. Not speaking for military and other high-level applications, vendors already have access to the true 3-D concepts describes herein and stand ready to sell a better tool when the consumer asks for it. A cliché from a business major is, "it all boils down to marketing." Maybe a qualifying phrase, "while avoiding snake oil" should be added in all promotions – including this one promoting true 3-D.

  Computing a distance between points is a source of tension between surveyors/engineers and GIS practitioners. It's a fact. . . a distance is distorted when projected from a curved surface to a mapping plane. Minimizing distortion to an acceptable level for surveying and mapping activities dictates a limit to the area that can be covered by a given map projection. The result is multiple projections to cover an area such as a state. On the other hand, uniqueness of location is critical in GIS applications and the integrity of a computed distance suffers when using a map projection that covers a larger area. With minimal accommodation, requirements of both GIS and mapping professionals can be satisfied simultaneously by using true 3-D and the GSDM.

  1. The ECEF coordinates are unique anywhere on/near Earth.
  2. There is no distortion of a computed distance between points in 3-D space.
  3. In either case, solid geometry equations are used to compute any desired geometrical feature. (With a change in mindset, you can have your cake and eat it too.)

- Emerging trends (digital twins, high-definition maps, spatial data accuracy):

  The concepts of digital twins (DTs) and high-definition maps (HDMs) currently enjoy the attention of many spatial data users and vendors who want to "get on the bandwagon." A DT is intuitive in that a DT is an electronic representation of the physical world. A DT can be very powerful. . .if not misused. The meta data associated with any DT applications should be unambiguous as to whether the end product is based on true 3-D or pseudo 3-D. Furthermore, any accuracy statement for any deliverable should clearly indicate "with respect to what."

  The reliability and success of automated mapping/navigation operations depends on the quality of position as determined (in real time) combined with the quality (positional accuracy) of the map against which the positional comparison is made. The concepts are identical whether the goal is targeting (military destruction or package delivery) or collision avoidance (lanes on the highway or airplanes in flight). A high-definition (electronic) map is plotted from geocentric coordinate differences ($\Delta X/\Delta Y/\Delta Z$) rotated to a user-selected local perspective. The user determines the quality of such a HDM by imposing a (selectable) filter on the statistics of points used.

  The GSDM supports both global and local accuracies but relies on user input of the observations (zeros on off-diagonals) or measurements (full covariance matrix) used in computing the position of each point. See discussion at http://www.globalcogo.com/EFB-SaGES-ALTA-NSPS.pdf.

- Modernization of the National Spatial Reference System (NSRS):

  The National Geodetic Survey (NGS) is modernizing the National Spatial Reference System (NSRS) and NGS personnel deserve enormous respect for the work they are doing. Their commitment to the end user is commendable as evidenced by plans to accommodate tectonic plate movement in the 3-D datum planned to be published in 2025. The geocentric X/Y/Zs of the new datum (and existing published values) used in conjunction with the GSDM provide the spatial data user great flexibility in manipulating and using spatial data in the 3-D environment. NGS also plans to publish a new vertical datum. Why? Except for certain scientific applications, the spatial data user community will be better served by using ellipsoid height for the third dimension. That is, using true 3-D and avoiding costs/burden of geoid modeling – see http://www.globalcogo.com/ImpactOfGravity.pdf.

  Map projections play an essential role in mapping horizontal positions. But map projections are strictly 2-D and have limited applications in the true 3-D environment. Yes, NGS is working with various stakeholders to develop low-distortion projections (LDPs) to be used in conjunction with the modernized NSRS. Those efforts are to be applauded because many in the user community are familiar with the current system of state plane coordinates and, as part of adapting to disruptive innovations, need to "walk before running." But, going forward, the proliferation of numerous LDP zones, layers, and complex transformation equations will eventually drive transition to a simpler integrated system such as the 3-D global spatial data model (GSDM).

Cut-to-the-chase:

The digital revolution has impacted many facets of human existence – in this case, spatial/geospatial data. Miniaturized sensors, data transfer rates measured in G-bytes per second, enormous (and inexpensive) storage capacity, lightning-fast computers, and sophisticated software all contribute to impressive spatial data handling capabilities. Not to discount such, but society stands to realize even more benefits from the digital revolution if spatial data users adopt and use a common true 3-D model for 3-D geospatial data. Returning to basics, and ignoring curvature of space-time, the spatial data community uses 7 types of spatial data. Distance is not listed separately as a spatial data type because distance is a primitive in each type listed. The 7 types are (ASCE, JSE Nov. 2001):

1. Absolute geocentric X/Y/Z coordinates of the Earth-centered Earth-fixed (ECEF) system.
2. Absolute geodetic coordinates of latitude, longitude, and ellipsoid height.
3. Relative geocentric coordinate differences, $\Delta X/\Delta Y/\Delta Z$.
4. Relative geodetic coordinate differences, $\Delta\phi/\Delta\lambda/\Delta h$.
5. Relative local coordinate differences, $\Delta e/\Delta n/\Delta u$ – right-handed, origin may be ambiguous.
6. Absolute local coordinates, e/n/u – right-handed, origin may be ambiguous.
7. Arbitrary local coordinates, x/y/z – right-handed, origin may be ambiguous.

The first four spatial data types are referenced to the Earth, the last three types lack specific definition as to an origin but can be used as true 3-D **– if flat-Earth assumptions are valid.** This is a source of ambiguity.

The GSDM can be instrumental in reducing (or eliminating) ambiguity in emerging concepts such as digital twins, high-definition maps, and spatial data accuracy.

Arguments of “this is the way we do it” and “it costs too much” are acknowledged and bode for continued use of pseudo 3-D. To the extent such arguments prevail, it is essential that “true 3-D” or “pseudo 3-D” be included as part of the meta data associated with any spatial data deliverable. Otherwise, arguments in support of true 3-D include (there are others):

1. A 3-D model should be used for 3-D geospatial data.
2. Earth’s center of mass is more stable and is easier to locate – making it the origin of choice.
3. Geometrical integrity of true 3-D is superior to that of pseudo 3-D.
4. Mathematical processing is more efficient with true 3-D – geoid modeling is not needed.
5. Equations are all public domain and much less complicated than computing on the ellipsoid.
6. Learning rules of solid geometry are less onerous than geodetic or map projection equations.
7. Many spatial data users can avoid geoid modeling and keeping track of LDP zones.
8. Users worldwide enjoy the use of common “simple” equations for computations in 3-D space.
9. Spatial data accuracy, both global/local, are easily computed, including “with respect to what.”

Conclusion:

Finally – Although the scope of this proposal may be covered by the NIST mission, the vision may be too great for any one entity. Will various “silos of interest” preclude success?

With the explosion of spatial/geospatial data applications worldwide, there are many groups and organizations that stand to benefit from “standardization” of a 3-D geospatial model. Although motivation for collaboration will vary, input should be solicited from:

1. International standards organizations/associations
2. International vendor organizations/associations
3. Government organizations – both military and civilian
4. Vendors – both hardware and software
5. Professional organizations/associations
6. Corporations and businesses
7. Academic and research institutions

References:

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