Systematic Error, Low-Distortion Projections (LDPs), and the 3-D Global Spatial Data Model (GSDM)

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June 2020
As Filed with the U.S. Copyright Office – September 4, 2020

Abstract

Given upcoming publication of the 2022 datums, the National Geodetic Survey (NGS) deserves kudos for doing what needs to be done with respect to defining map projections and promoting the use of low-distortion projections (LDPs). However, the presumption in this article is that the integrated 3-D global spatial data model (GSDM) will eventually supplant the use of a 2-D map projection for many applications. Why? Unlike the GSDM, LDPs routinely contain some systematic error distance distortion. Random error and systematic error are different. In the case of an LDP, small systematic errors can justifiably be treated as random errors. That justification has two parts, 1) what geometry and how much effort (what) is required to compute the systematic error? And 2), is the computed systematic error (a correction) large enough to matter? The geometry and computational effort will be covered in a separate paper. This paper looks at the random/systematic error trade-off and promotes the GSDM as a viable alternative to the map projection model. One possible conclusion is that the advantages of using the GSDM for spatial and geospatial data manipulation will outweigh the convenience of using an LDP.

Key Words

Low-distortion projection (LDP), distance distortion, random error, systematic error, model, spatial data, global spatial data model (GSDM)

Introduction

Cartographers use map projections to “flatten the Earth” thereby facilitating human visualization of features on or near the Earth’s surface. It is well known that the Earth’s curved surface cannot be represented on a flat map without geometrical distortion. It is equally accepted that a small portion of the curved Earth can be represented on a map with very little (insignificant) distortion. The challenge when designing a map projection is to balance the definition of “small” with the interpretation of “insignificant.” Part of that challenge is met by using a conformal map projection in which an angle on the curved surface is transformed to the map without distortion. Consequentially, the area of a parcel (a geometrical figure bounded by lines) and the distance between named points are both distorted during the transformation from a curved surface to a plane. Such a mathematical bi-directional transformation includes only two dimensions. By itself, a map projection does not accommodate the third dimension – elevation is handled separately. Practice in various disciplines has come to rely on 3-D digital geospatial data and the advantages of using the integrated 3-D global spatial data model (GSDM) to handle spatial and geospatial data warrants consideration because it preserves geometrical integrity in 3-D space. Distortion of area is not discussed in this article.

Historical

Designs of a conformal map projection for surveying/mapping/engineering have focused on the trade-off between the amount of distance distortion permitted and the geographical area to be covered by the projection. The Universal Transverse Mercator (UTM) projection is an example of relaxing the distance distortion criterion in favor of enlarging the geographical area coverage and the existing U.S. state plane coordinate system (SPCS) is an example of limiting distance distortion – thereby restricting the geographical coverage of a given projection. The distance distortion limit adopted for the UTM zones is 1 in 2,500 (1:2,500) while a 1 in 10,000 (1:10,000) distance distortion limit was adopted (for the most part) for zones within the original SPCS. Although implications for UTM projections could be relevant, the UTM projection is not considered further in this paper. The remaining discussion includes the traditional SPCS (1:10,000), low-distortion projections (LDPs), and the GSDM.

The original SPCS zones were defined in the 1930s and transit/tape surveys (routinely 1:7,500 or less) were a standard part of local practice. It was felt that a distance distortion of 1:10,000 in the projection could be tolerated in traverse computations without detrimental consequence. In cases where it did matter, the systematic error caused by the grid scale factor could be computed and applied as a correction (Mitchell and Simmons 1945). The reduction to sea level was identified as the elevation factor and the combined factor was defined as the product of the grid scale factor and the sea level factor. But adoption and use of the SPCS did not advance rapidly, in part, because elevation was not part of the initial design. In practice, the difference between a measured horizontal ground distance and its representation on the mapping grid involves both the grid scale factor and the elevation factor for the line. Specifically, the grid distance used in state plane coordinate computations is determined as:

$$Grid\ distance = horizontal\ ground\ distance * grid\ scale\ factor * elevation\ factor. \quad (1)$$

Trade-offs

Equation 1 is not difficult to use but leading professionals should understand the inherent trade-offs in each term and should be able to evaluate them. Perhaps the most fundamental trade-off is to determine at what level an identified systematic error can be included in the random error budget – i.e., ignored without detrimental consequence. In the era of transit/tape surveys a ratio-of-precision of 1:7,500 might be associated with a “good” survey. Moving on to theodolite/EDM data collection, a ratio-of-precision could routinely be expected to be in the range 1:20,000 to 1:50,000 or better. When using modern instrumentation (e.g., GNSS for geodetic surveys), the conscientious spatial data user might be dissatisfied with any ratio-of-precision less than 1:100,000. Can a distance distortion greater than 1:50,000 be acceptable for “standard” surveying and mapping practice? Such a moving target implies that the trade-off evaluation should include two separate considerations, i.e., both standards and specifications. What level of refinement (also known as positional tolerance) is needed to meet the standards and what resources (equipment and procedures) are required by the specifications? Several examples of standards include the Federal Geographic Data Committee (FGDC) accuracy requirements for various categories of surveys (FGDC 1998 – geodetic), the ALTA/NSPS Minimum Standards for Land Title Surveys (ALTA/NSPS 2016), and Minimum Standards for Surveying in New Mexico (NM BOL 2016). The nature of standards is such that they change slowly (periodic updates do occur) but specifications tend to be more “fluid” (subject to user discretion).

As a reminder, the result of any trade-off evaluation should be that the public is well-served by dedicated professionals who understand and take responsibility for the consequences of the analysis. Separate from this article, the author has embarked on a project to investigate "the role of a model" (Burkholder 2019a) in support of the hypothesis that the best model is the simplest model that is adequate for the application. Admittedly, "adequate for the application" is a subjective criterion and leaves room for user judgement and experience. Another important consideration is deciding what is "simple." That decision may be influenced by the complexity of mathematical operations inherent in the model or "simple" may also be judged by how easy (and/or inexpensive) it is to buy and use a software solution. In all cases, including "black box" solutions, the public deserves to be served by knowledgeable professionals capable of understanding, evaluating, and implementing the trade-offs.

Approximations are often handled routinely one-at-a-time. But, when considering an aggregate of approximations, the evaluation can become more of a challenge. For example, depending on the "exactness" of the desired result (in this case, a grid distance), various issues can affect the outcome. The terms on the right side of Equation 1 include both measurements (with standard deviations) and assumptions relative to the geometry used in the computations. Can those assumptions be both adequate and simple? The focus of this article is on the "adequate" while "simple" will be covered in a separate article. See www.globalcogo.com/simple.html.

Horizontal distance (HD) For flat-Earth applications, the definition of horizontal distance is the right triangle component of a slope distance. But when using longer distances or when attempting to preserve mathematical rigor, a better definition of horizontal distance may be needed. Examples of horizontal distance definitions given by Burkholder (1991) include:

- HD is the right triangle component of a slope distance.
- HD is the tangent plane distance between the plumb lines of the endpoints.
- HD is a chord distance having the same elevation at both ends of the line.
- HD is the arc distance between end points of a line at a specified elevation.
- HD is the mean sea level (geoid) distance between plumb lines.
- HD is the distance along the geodesic between plumb lines.

The difference may be inconsequential but, when using stored coordinate data, a computed horizontal distance is taken to be between the ellipsoid normals rather than between the plumb lines at the endpoints (Burkholder 2019b).

A mathematically rigorous definition of "horizontal distance at elevation" is given by Rollins/Meyer (2019) as "the length of the straightest curve (geodesic) between two points, A and B, lying on an elevated reference surface."

Grid scale factor Grid scale factor at a point is defined (Stem 1989) as the ratio of an elemental distance on a map grid divided by the corresponding elemental distance on the ellipsoid. The grid scale factor changes slowly as one moves point to point throughout the projection area. Exceptions, depending on the projection type, are that the grid scale factor does not change if moving north/south on a transverse Mercator projection or east/west on a Lambert projection (the direction of uniform grid scale factor on an oblique Mercator projection is neither north/south nor east/west). Beyond those conditions, computing the grid scale factor for a line involves an approximation due to its changing nature. Stem (1989 pages 49 & 50) describes several popular options. Other (more esoteric) mathematical procedures may also be implemented (Meyer 2010, page 126). A summary of options and nominal ranges for horizontal distance includes:

- Use the grid scale factor at any point on the line for the entire line.
  (Nominal range – up to about 1 km)
- Use the average of the endpoint grid scale factors for the entire line.
  (Nominal range – up to about 4 km)
- Use the grid scale factor at the middle of a USPLSS section for the entire section.
  (But not for control surveys, geodetic surveys, or engineering surveys.)
- Use the grid scale factor at a chosen point for (or at middle of) the entire job/project.
  (Subject to the geographical extent of the project and the accuracy required.)
- Use a Simpson's one-sixth rule grid scale factor for the entire line (Stem 1989).
  (Appropriate for lines up to about 6 km long – beyond that ????)

If demanding criteria are to be met, the nominal guidelines for grid scale factor as given above may not be appropriate.

Elevation factor Under flat-Earth assumptions, horizontal distance is the same at any elevation. Beyond flat-Earth assumptions, horizontal distance is elevation dependent (Burkholder 1991). That difference can be significant when attempting to preserve the geometrical integrity of the observations. Burkholder (2004) includes a detailed analysis of the elevation factor that addresses the following questions:

- At what elevation should the elevation factor be computed - at one end or midpoint of the line?
- Should orthometric height (elevation) or ellipsoid height be used?
- How many significant figures are needed for the radius of the Earth to be used?
- How is the quality of a computed elevation factor affected by the uncertainty of Earth radius and ellipsoid height/elevation?
- Can the difference caused by the elevation factor be treated as a random error or as a systematic error?

Combined factor Combined factor is defined as the grid scale factor times the elevation factor (Mitchell & Simmons 1945 and Stem 1989). Equation 1 is written as:

$$Grid\ distance = horizontal\ ground\ distance * combined\ factor. \qquad (2)$$

When using Equation 2, choosing the appropriate horizontal distance definition may become critical. Separately, the impact of the combined factor may be more important because (1) the grid scale factor is an approximation that may or may not be appropriate (unless one of the more esoteric methods is used), and (2) the elevation factor can be different depending on the assumptions made by the user (or programmer). Due to its changing nature and inherent approximations, blindly computing and using the grid scale factor for long lines (especially over 10 km) should be avoided. The GSDM does not need or use the combined factor. But the GSDM provides a closed form equation (no approximation) for computing the combined factor for lines of any length (Burkholder 2016). Understandably, computation of a combined factor can become meaningless if the definition of horizontal distance is not chosen carefully. The importance of metadata (documenting measurement circumstances and assumptions implicit in subsequent computations) is highlighted as being an essential part of the trade-off evaluation for any map projection application - including LDPs.

Levels of LDP distance distortion are often shown in colored graphical form on a map (known as a heat map). The implication in using an LDP is that distance distortion can be treated as a random error within those tolerance levels. In many, if not most, cases, the distance distortion within those areas can be ignored unless greater precision is required or if elevation difference assumptions are violated. An important point which needs to be made is that "improved" surveying practice includes computing the combined factor systematic error and applying it as a correction. Applying the systematic error correction means that the geometrical integrity of a survey can be enhanced. The irony is that if the combined factor really is 1.0000000, a foot is still a foot. Otherwise, if the systematic error is computed and applied as a correction, a foot is no longer a foot. Other length units – meters, miles, etc. – are likewise impacted. Understandably, this can be a forceful argument in favor of using an LDP – in those cases where the distortion is sufficiently small. Of course, most disciplines (and users) pay attention to the level of distortion that can be tolerated for given applications and those considerations weigh heavily in writing standards and specifications. But that tipping point becomes a moving target in a trade-off analysis if/when those criteria cannot be counted on to be universal or static.

Burkholder (2020) is a conceptual item that describes the relationship between accuracy/precision and random/systematic error. The impact of any unmodeled systematic error can be described in terms of actual distance or, more commonly, in terms of ratio of precision or parts-per-million as shown below.

			Typical survey tolerances
1:1,000,000	one part per million	1 ppm	Laboratory quality GPS
1:500,000	two parts per million	2 ppm	High-grade GPS control
1:100,000	ten parts per million	10 ppm	Routine careful GPS
1:50,000	twenty parts per million	20 ppm	Run-of-the-mill GPS
1:20,000	fifty parts per million	50 ppm	Careful total station data
1:10,000	one hundred parts per million	100 ppm	Careful transit/tape survey

The Global Spatial Data Model (GSDM)

The GSDM (Burkholder 1997) is an alternative to using an LDP (or any map projection) because it can simultaneously serve the needs of both surveying/engineering communities and GIS disciplines. Features of the GSDM include:

- The GSDM has been defined and evaluated. Challenges have been successfully refuted. (see - https://ascelibrary.org/doi/full/10.1061/%28ASCE%29SU.1943-5428.0000274)
- The GSDM models spatial data in 3-D space without distorting angle or distance measurements.
- The GSDM is compatible with using 3-D digital spatial data. 2-D is supported subordinate to 3-D.
- The GSDM is already in place. Computations are based on stored geocentric X/Y/Z values.
- The GSDM is built on X/Y/Z coordinates. Datum updates are identified by naming the epoch used.
- The GSDM equations are all in the public domain and applicable worldwide (sans pole areas).
- The GSDM solid geometry equations are not as complex as geodesy and mapping equations.
- The GSDM inverse gives ground level horizontal distance and the true azimuth point to point.
- The GSDM has no need for projection constants, grid scale factors, or elevation factors.

- The GSDM includes a stochastic model for propagating measurement uncertainties.
- The GSDM provides a way for the user to compute the uncertainty of any derived quantity.

The GSDM (Burkholder 2016) can be used to compute the combined factor between any two points with no approximation as:

$$Combined\ factor = \frac{Grid\ Distance}{Horizontal\ Ground\ Distance} \qquad (3)$$

Admitting an obvious bias by the author in the points just made, Meyer (2010, pages 75 & 76) gives both advantages and disadvantages to using X/Y/Z coordinates (the GSDM). While the advantages listed by Meyer are mostly included in the points above, it seems that the disadvantages he lists can be categorized as “preference” as opposed to “deficient.” The last disadvantage listed by Meyer is quite correct that an X/Y/Z inverse does not follow the curved surface of the Earth. That could also be viewed as an advantage because the GSDM provides a simple (Pythagorean Equation) closed from computation of the 3-D distance between any two points (Burkholder 2019b) and the user has the option of choosing and/or using subordinate geometry (2-D features from 3-D data) to match the problem to be solved. A general statement is that the disadvantages listed by Meyer can be mitigated to the extent one becomes more familiar with the relationships of geometrical elements in 3-D space.

Background for Trade-off Evaluation

The original state plane coordinate zones were designed in the 1930s without including elevation as a design criterion. But, attempting to make state plane coordinates more acceptable for routine surveying practice, University of Michigan Professor Ralph Moore Berry developed state plane coordinate zones and algorithms for Michigan based on a reference elevation of 800 feet above sea level (page 1, USC&GS 1965). Most of the topography in Michigan lies within 200 feet of that design elevation. The thought was that, within that range, the elevation factor could be safely ignored for all but the most precise surveys. Experience validated that assumption, but other issues became a nuisance.

Michigan State Plane Coordinate System (MSPCS) The MSPCS was adopted by the Michigan Legislature in 1964. Professor Berry was a mentor to the author who earned a BSCE from the University of Michigan in 1973. Following graduation, he was employed by Commonwealth Associates, Inc. of Jackson, Michigan, and his responsibilities included (among others) performing the survey computations for more than 93 miles of high-voltage transmission line corridor in eastern Michigan (Burkholder 1975). Although that 765 kV transmission line was never built, the control surveying and parcel surveying portion of the corridor was quite successful.

An issue becoming a nuisance on the transmission line project was that the concept of using state plane coordinates was “foreign” to most practicing professionals and software vendors. An inconsistency in federal publications was also bothersome (Appendix C, Burkholder 1980). Used properly, the design objective of the elevated reference surface for the State of Michigan was realized and very beneficial. But with the datum transition from NAD 27 to NAD 83, the reference surface in Michigan was returned to the ellipsoid. Several reasons, based in part on information in Burkholder’s MS Thesis (1980), included:

- Using the standard ellipsoid would retain consistency in literature, ellipsoid/zone parameters, and practice.
- Survey practice in the early 1980s had advanced beyond transit/tape surveys and included more sophisticated measurements, e.g., EDM and theodolites. Consequentially, ignoring inherent systematic errors had the potential of "polluting" routine traverses, and
- Computers and software were now (in 1983) readily available for including, previously ignored, systematic errors in the distance reductions.

Local Coordinate Systems With advent of GPS and spatial data being used by more disciplines (GIS etc.), the grid/ground difference remained a concern. Nancy von Meyer (1990) wrote about possible benefits of using county coordinate systems in which the grid scale factor and the elevation factor were both included as design parameters for a given zone. By including elevation in the projection design and bounding the geographical extent of a zone, say to a county, the impact of the combined factor could be kept within an acceptable level of distortion. Although not including transformation algorithms, von Meyer's article mentions their importance and the article concludes, "Countywide projections and coordinate systems can have better nominal accuracies than regional or statewide systems and still allow direct data sharing between county, regional, state, and federal GIS/LIS systems." Given prior experience with the MSPCS, Burkholder (1993) wrote an article in support of von Meyer's 1990 paper and included specific algorithms for computing local coordinates. Those algorithms are essentially the same as those in Stem (1989) except that – following the procedure used by NGS for the MSPCS on NAD 27 (USC&GS 1965, page 1) – the semi-major axis of the ellipsoid for a local projection is increased by the user-selected reference height. The flattening value was not changed. That process is referred to by Armstrong et. al. (2014, 2017) as "scaling the ellipsoid."

There are others, but subsequent notable implementations of "local coordinate systems" include the State of Minnesota (Whitehorn 1997), Wisconsin (Wisconsin State Cartographer's Office 1995 and 2009), and Oregon (Armstrong et.al. 2014 and 2017). The mathematical process of raising-the-reference-surface has varied from case to case. A solution espoused by some was to multiply legitimate state plane coordinates by the elevation factor of the job or project. While the resulting grid inverse provided better agreement between grid and ground distances, that method fell into immediate disfavor because the "modified" state plane coordinates could be (and sometimes were) mistaken for the real thing.

Low-Distortion Projections Characteristics of LDPs being recommended by NGS include (NGS 2019a) :

- State plane coordinate systems will be based on the 2022 datums defined by the NGS.
- The GRS 80 ellipsoid remains the standard ellipsoid for all SPCS zones.
- Reference surface ellipsoid height is defined implicitly by modifying the scale reduction of the projection axis instead of scaling ellipsoid parameters.
- A single-parallel Lambert projection replaces the two-standard parallel system used previously.
- Each state will have a single statewide zone. Maximum distance distortion will vary according to size/configuration of the state and average topography.
- A state can optionally also have additional LDP zones, each designed at the topographic surface. The design of each additional zone will be reviewed and approved by NGS.

- Lacking input from a state, NGS will design a “default” SPCS zones similar to existing NAD 83 zones except that the projection axis will be scaled to raise the projection surface to approximate the topography in the zone coverage.
- Coordinates of each mathematical origin will be selected to avoid coordinate overlap and possible confusion with previously used coordinate ranges.
- The goal is for transformation equations to be accurate within 0.01 mm.
- SPCS2022 coordinates will be published in meters. Optionally, foot units will also be provided where 1 foot = 0.3048 meter exactly. The U.S. Survey Foot will be deprecated by the federal government December 31, 2022 (FRN 2019) and thereafter be treated as legacy data.

Design Considerations for Optional Zones According to NGS (2019b), the **linear distortion design criterion** is the smallest specific distortion range of ±5, ±10, ±20, ±30, ±40, ±50, ±75, ±100, ±150, ±200, ±300, or ±400 ppm that satisfies all three of the following minimum percentages:

- 90% of zone population.
- 75% of cities and towns (based on location only, irrespective of population).
- 90% of total zone area.

These criteria were promulgated to provide guidance to those who contemplate establishing specific LDPs for given areas and applications. In New Mexico for example, the City of Las Cruces and the City of Albuquerque (Dona Ana and Bernalillo counties respectively) both contemplate implementing an LDP to be used on the 2022 datum based on the North American Terrestrial Reference Frame of 2022 (NATRF2022). NGS (2019b) has established processes to handle requests for additional LDPs.

Drawbacks

As a reminder, the rigor of LDPs is well-established and applications of LDPs in various places have been shown to be very beneficial – especially in areas of modest elevation differences. The NGS has devoted considerable effort and committed significant resources to providing tools for access to an improved NSRS once the 2022 datums are published. Such efforts are to be recognized and applauded. It is important, however, to recognize and discuss the drawbacks associated with transition to the NATRF2022. These in include but are not necessarily limited to:

- The map projection model is strictly 2-D. Modern measurement systems routinely collect, and users rely on, 3-D digital spatial data.
- Distance distortion can be conveniently controlled within given portions of a map projection zone but areas of significant elevation differences present additional challenges.
- Even though the difference may be small and “controlled,” the fact remains that a “foot is not a foot” whenever a map projection distance it used.
- The “tipping point” for tolerance limits has evolved from 1:10,000 on NAD 27 to tighter limits resulting from the evolution of technology and enhanced user capability. Without a crystal ball, it is impossible to predict what the tipping point will be in the future.
- Even though it is possible to compute systematic errors and apply corrections in those cases when greater precision is needed, routine application of such corrections will be accomplished only with added time and effort by the user.

- Due to the complexity of underlying geometry, obscure algorithms, and imperfect understanding of distortion limits, the potential for misuse of LDPs remains a challenge. (Note, the complexity of equations and processes associated with a map projection are discussed in a separate paper.)
- Even with NGS administration of details for numerous zones, the proliferation of zones and overlap of zones will be a source of confusion for some users.

Examples

The following examples are provided to put “meat on the bones” of the points made in this article. Although much of the information is posted on the Global COGO web site, the information is organized better in two books published by CRC Press, “The 3-D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure” and the 2nd Edition, “The 3-D Global Spatial Data Model: Principles & Applications.” Both are available from CRC Press or can be found via an internet search.

The 2008 edition of the 3-D book contains a detailed example of a GPS network on the NMSU campus which includes three different weighting options for the adjustment. It also includes computation of both network and local accuracy for option three using the full covariance matrices of each point-pair. A second example shows a “no distortion” 2-D plat generated from a 3-D GPS survey covering a local section of the U.S. Public Land Survey System (USPLSS). The plat includes local tangent plane distances and azimuths as well as standard deviations of each. A link to a GPS leveling project is also included in the book. All three projects were computed on NAD 83 (1992).

The following examples are included in the 2008 edition of the 3-D book.

Comprehensive network adjustment for points on NMSU campus.
www.globalcogo.com/nmsunet1.pdf NAD 83 (1992)

A “no distortion” 3-D GPS survey used to develop a 2-D plat of USPLSS Section.
www.globalcogo.com/3Dgps2Dplat.pdf. NAD 83 (1992)

GPS survey used to determine NAVD 88 elevation of HARN station REILLY on NMSU campus.
www.globalcogo.com/gpselev1.pdf NAD 83 (1992)

The 2018 2nd Edition of the 3-D book repeats the previous examples plus additional projects. Chapter 15 in the 2nd Edition documents 12 different 3-D projects which are summarized at www.globalcogo.com/3D-projects.html. Several examples relating specifically to land surveying, map projections, and LDP issues include:

Example 3 uses terrestrial observations to determine the 3-D location of the finial atop Skeen Hall (NMSU classroom building - http://www.globalcogo.com/SkeenHall-NMSU.pdf). Horizontal and vertical (zenith) angles were observed to the top of the finial from three different 3-D control points. Reducing the observations to equivalent 3-D vector components and computing a linear least squares adjustment, it was possible to determine the 3-D position of the top of the finial within 3 cm in all three components at the 95% confidence level.

Example 5 is based on reliable X/Y/Z coordinates for two points – the SW Corner of Section 31 in the 2-D plat example described above and New Mexico's Initial Point. Both points lie on the NM Principal Meridian and a 3-D inverse between them shows that the original surveyors maintained true north of the NM Principal Meridian within 40 seconds of arc. Using the Pythagorean inverse, $D = \sqrt{(\Delta X^2 + \Delta Y^2 + \Delta Z^2)}$, the 3-D spatial distance between the two points (222 km or 138 mi.) can be computed without approximation. The example shows how other distances (arc, chord, etc.) can be computed from the 3-D distance. The reader is invited to investigate the definition of horizontal distance – see Figure 7 of http://www.globalcogo.com/HD-Options.pdf.

Example 6 includes points on the NM/TX boundary purporting to mark the location of the Rio Grande River as it existed in 1852 – see http://www.globalcogo.com/NM-TX.pdf. Texas and New Mexico argued about the location of the boundary after NM became a state in 1912. The U.S. Supreme Court stepped in, commissioned a survey, constructed monuments, and published a report in 1929 which documents the location of the boundary. Table 15.11 in the 2nd Edition shows an interesting comparison of GPS vectors observed in 2005 and 2006 with some of the courses taken from the U.S. Supreme Court document. Where is the corner if the monument is http://www.globalcogo.com/leaning.pdf.

Example 10 determines the latitude/longitude (or the 3-D) position of the center of the desk in the office of the Associate Dean of Engineering at NMSU. It is a "gee whiz" exercise with an ulterior motive. The example demonstrates three different methods for coming up with the same answer – by traditional geodesy, by using state plane coordinates, and by using the 3-D GSDM. Observations consisted of making a side-shot from HARN station REILLY using the Skeen Hall finial (example 3 above) as the backsight. The point was not marked on the desk and the desk was not attached to the floor. The value of the exercise lies in comparing the three computational methods, not in the unsaved location of the point.

Example 12 shows the efficiency by which a parallel of latitude can be laid out using the GSDM. Currently there may be little demand for laying out new parallels but the GSDM can be a valuable tool in "retracing steps of the original surveyor" - http://www.globalcogo.com/parallel.pdf

Defensible Conclusions

Readjustment of the national geodetic control network in the United States – targeted for completion in 2022 – is a given. In accordance with its mission, NGS is committed to providing public access to the National Spatial Reference System (NSRS). The surveying/engineering community has, for many years, enjoyed access to the horizontal geodetic network by way of the SPCS. With the advent of the digital revolution, the spatial data user community also now relies heavily on access to the NSRS as the foundation for GIS applications. But criteria for serving the GIS community are different than those for the surveying/engineering communities. Ideally, the SPCS policies for the 2022 datum will be able to accommodate both user communities. The surveying/engineering communities need access in a manner that preserves geometrical integrity while the GIS communities need big-scale compatibility and uniqueness more than geometrical integrity. That comes down to the conflicting requirements and trade-offs discussed in this article. Map projections are considered the tool for both cases – an LDP for the surveying/engineering communities and a separate large-area projection to serve the spatial data user communities.

Many will legitimately conclude that an LDP is an acceptable solution for portraying a curved surface on a flat map. Using appropriate design criteria and separate zones, both the engineering and GIS communities can be served. Trade-offs discussed in this article may be inconsequential. But is it possible that such a conclusion (at least in some areas) may be premature? Given the ability of the GSDM to accommodate all users and all applications, the trade-offs listed in this paper should be considered and discussed openly – especially in and for those areas where, due to elevation differences and/or distance from the central projection axis, the ppm distortion may exceed an acceptable limit. Choosing an appropriate model needs to reflect both criteria – is the model adequate and simple?

Another legitimate conclusion is that the GSDM is the preferred model for many spatial and geospatial data applications. Use of the GSDM does NOT preclude use of other models in and for those applications for which the GSDM is deemed not adequate.

It should also be noted, the proliferation of LDP zones represents potential for significant confusion and possible misuse. The NGS is to be commended for imposing administrative oversight and strict conditions on the establishment of LDP zones within the redefined SPCS. Recent and ongoing efforts by NGS to provide resources for enhancing geospatial literacy for spatial data users are recognized and commended.

Acknowledgments

This article was improved by incorporating helpful suggestions made by Thomas Meyer, PhD; University of Connecticut and Glen Schaefer, PE, PLS; geodetic engineer retired from the Wisconsin Department of Transportation.

References

ALTA/NSPS 2016, “Minimum Standard Detail Requirements For ALTA/NSPS Land Title Surveys,” American Land Title Association, Washington, D.C. and National Society of Professional Surveyors, Frederick, MS.

Armstrong, M.L., J. Thomas, K. Bays, M. Dennis; 2014, “Oregon Coordinate Reference System – Handbook and User Guide, Version 2.01,” Oregon Department of Transportation, Highway Division, Geometronics Unit, Salem, Oregon. https://docplayer.net/13920311-Oregon-coordinate-reference-system.html

Armstrong, M.L., J. Thomas, K. Bays, M. Dennis; 2017, “Oregon Coordinate Reference System – Handbook and Map Set, Version 3.01,” Oregon Department of Transportation, Highway Division, Geometronics Unit, Salem, Oregon. https://www.oregon.gov/ODOT/ETA/Pages/OCRS.aspx

Burkholder, E.F., 1975, “Practical Application of the Michigan State Plane Coordinate System,” Presented at the 34th Annual Conference of the Michigan Society of Registered Land Surveyors, Bay City, Michigan, February 19, 20, and 21, 1975. www.globalcogo.com/MSPCS1975.pdf

Burkholder, E.F., 1980, “A Metric Map Projection for the State of Michigan” Master’s Thesis, Purdue University, West Lafayette, Indiana, May 1980. http://www.globalcogo.com/EFB-Thesis-1980.pdf

Burkholder, E.F., 1991, “Computation of Horizontal/Level Distances” Journal of Surveying Engineering, Vol. 117, No. 3.

Burkholder, E.F., 1993, “Design of a Local Coordinate System for Surveying, Engineering, and LIS/GIS,” Surveying and Land Information Systems, Vol. 53, No. 1, 1993, pp 29-40. http://www.globalcogo.com/localcor.pdf

Burkholder, E.F., 1997, “Definition and Description of a Global Spatial Data Model (GSDM),” filed with the U.S. Copyright Office, Washington, D.C, April 1997. http://www.globalcogo.com/gsdmdefn.pdf

Burkholder, E.F., 2004, “Accuracy of Elevation Reduction Factor,” Journal of Surveying Engineering, Vol. 130, No. 3.

Burkholder, E.F., 2016, “Using the Global Spatial Data Model to Compute Combined Factors,” Journal of Surveying Engineering, Vol. 142, No. 4.

Burkholder, E.F., 2019a, “Role of a Model,” Abstract only. http://www.globalcogo.com/rolemodel.pdf

Burkholder, E.F., 2019b, “Horizontal Distance Options Supported by the 3-D Global Spatial Data Model (GSDM),” filed with the U.S. Copyright Office, Washington, D.C., April 2019. http://www.globalcogo.com/HD-Options.pdf

Burkholder, E.F., 2020, “Exploring Spatial Data Accuracy Concepts,” Point of Beginning (POB), Vol. 45, No.6, March 2020, Troy, Michigan. https://www.pobonline.com/articles/102099-exploring-spatial-data-accuracy-concepts

Federal Geographic Data Committee (FGDC) 1998, “Geospatial positioning accuracy standards, part 2, Standards for geodetic networks,” Reston, VA: Federal Geographic Data Committee, U.S. Geological Survey. https://www.fgdc.gov/standards/projects/accuracy/part2/chapter2

Meyer, T.H., 2010, *Introduction to Geometrical and Physical Geodesy: Foundations of Geomatics*, ESRI Press, Redlands, CA.

Mitchell, H.C. and L. Simmons, 1945, “The State Coordinate Systems (A Manual for Surveyors),” Special Publication No. 235, U.S. Department of Commerce, U.S. Coast & Geodetic Survey, Washington, D.C. https://geodesy.noaa.gov/library/pdfs/Special_Publication_No_235.pdf

National Geodetic Survey (NGS) 2019a, “State Plane Coordinate System of 2022 Policy,” Policy Document NGS 2019-1214-02, Silver Spring, MD. https://geodesy.noaa.gov/INFO/Policy/files/SPCS2022-Policy.pdf

National Geodetic Survey (NGS) 2019b, “Procedures for Design and Modification of the State Plane Coordinate System of 2022,” Procedures Document NGS 2019-1214-01-A2, Silver Spring, MD. https://geodesy.noaa.gov/INFO/Policy/files/SPCS2022-Procedures.pdf

New Mexico Board of Licensure for Professional Engineers and Professional Surveyors (NM BOL), 2016, “Minimum Standards for Surveying in New Mexico, Title 12, Chapter 8, Part 2, New Mexico Administrative Code, Effective July 24, 2016, Santa Fe, NM. http://www.sblpes.state.nm.us/uploads/FileLinks/3a22dfad719d4b208229a6ac3d17b69c/2016_NM_Min_Standards_Surveying_1.pdf

USC&GS 1965, “Plane Coordinate Projection Tables for Michigan,” Publication No. 65-3, U.S. Department of Commerce, Coast & Geodetic Survey (now National Geodetic Survey), Rockville, MD. https://www.ngs.noaa.gov/INFO/Publications_Booklet.pdf or www.globalcogo.com/Pub65-3.pdf

von Meyer, N., 1990, “County Coordinate Systems,” ACSM Bulletin Number 126, June 1990, American Congress on Surveying & Mapping, Bethesda, MD. www.globalcogo.com/vonMeyer1990.pdf.

Rollins, C. and T. Meyer, 2019, “Four Methods for Low Distortion Projections,” Journal of Surveying Engineering, Vol. 145, No. 4. https://ascelibrary.org/doi/10.1061/%28ASCE%29SU.1943-5428.0000295

Stem, J., 1989, “State Plane Coordinate System of 1983,” NOAA Manual NOS NGS 5, Rockville, MD. https://www.ngs.noaa.gov/PUBS_LIB/ManualNOSNGS5.pdf

Whitehorn, K.L., 1997, “The Minnesota County Coordinate System: A Handbook for Users,” Precision Measuring Systems, St. Cloud, MN. https://www.worldcat.org/title/minnesota-county-coordinate-system-a-handbook-for-users/oclc/41493161

Wisconsin State Cartographer’s Office 1995, “Wisconsin Coordinate Systems,” Wisconsin State Cartographer’s Office, Madison, WI.

Wisconsin State Cartographer’s Office 2009, “Wisconsin Coordinate Reference Systems, 2nd Ed.” Wisconsin State Cartographer’s Office, Madison, WI. https://www.sco.wisc.edu/wp-content/uploads/2017/07/WisCoordRefSys_June2015.pdf