Journal of Geographic Information System, 2026, 18(2), 128-141
https://www.scirp.org/journal/jgis
ISSN Online: 2151-1969
ISSN Print: 2151-1950

GIS Distances and Directions Directly via the GSDM

Earl F. Burkholder[1,2]

[1]Global COGO, Inc., Las Cruces, NM, USA
[2]Emeritus Faculty, Surveying Engineering, New Mexico State University, Las Cruces, NM, USA
Email: eburk@globalcogo.com

How to cite this paper: Burkholder, E.F. (2026) GIS Distances and Directions Directly via the GSDM. *Journal of Geographic Information System*, **18**, 128-141.
https://doi.org/10.4236/jgis.2026.182007

Received: February 2, 2026
Accepted: March 16, 2026
Published: March 19, 2026

Abstract

Geographic Information Systems (GISs) are used extensively in various disciplines worldwide. Driven by the digital revolution, those systems have evolved to include, among others, principles of science, engineering, mapping, data collection, and spatial data management practices. Consequently, the appetite for spatial data has exploded as end users find additional ways to exploit the benefits of using 3D digital spatial data. Map projections are a fundamental component of a GIS and serve as a bridge between measurement and application. The 3D Global Spatial Data Model (GSDM) has emerged as an alternative to the conformal map projection model and offers significant benefits to spatial data users worldwide. Admittedly using the GSDM can be disruptive to existing practice and well-established policies should not be modified without proper justification. The ultimate impact of Artificial Intelligence (AI) on spatial data applications is not yet known. Although AI and the GSDM might be viewed as compatible, unwanted consequences of using AI are to be avoided. Aside from considerations enumerated elsewhere, the purpose of this article is to highlight efficiencies that can be realized by using the GSDM to compute local (plane surveying) directions and distances as incorporated in a GIS (even with AI).

Keywords

GIS, GSDM, Digital Spatial Data, Conformal Map Projections, Plane Surveying

1. Introduction

GIS professionals and technicians both work extensively with geospatial data in providing services to society. Spatial data are the raw material while people, businesses, agencies, and organizations are the clients. The Global Spatial Data Model (GSDM) provides an efficient geometrical bridge between the raw data (observations) and the end uses (applications). Coordination of policies (professionals) and practices (technicians) will enhance efficiency and provide additional benefits for all parties working with 3D digital spatial data. While reasons for adopting the GSDM as a matter of policy have been discussed elsewhere [1], the focus of this article is applications of spatial data in 2D practice.

Acknowledging that policy and practice are interrelated and that professional/technical considerations are not mutually exclusive, it is anticipated that additional discussions will be needed in developing standards and specifications associated with a transition to using a "3D model for 3D data". Questions of coordinate uniqueness, distance distortion, and meridian convergence are inherent in using a 2D map projection. Those issues are addressed by the GSDM which, by performing computations in 3D space, avoids the need for a conformal map projection and directly connects the spatial data primitive to local horizontal distances, directions, and elevations.

2. Prior Work

The digital revolution is characterized by transition from analog to digital in how information is collected, processed, stored, and used. Of many types of information affected, spatial data are the focus of this article. "Disruptive innovation" is encountered as methods conforming to properties of digital information supplant more traditional procedures.

Understanding that the ability to do something does not necessarily justify doing it, the transition to "using a 3D model for 3D data" deserves careful evaluation and justification. In addition to the practice procedures highlighted in this article, prior work provides a solid foundation on which to build a rigorous model for 3D digital spatial data.

- Appendix C in Bomford [2] provides an authoritative summary titled "Cartesian Coordinates in Three Dimension". Rigorous solid geometry equations for spatial data computations are long-standing.
- In 1978, world-renowned geodesist Helmet Moritz (1933-2022) [3] discusses "The Basic Rectangular Coordinate System" and in "The Reference Ellipsoid" section, he comments on the simplicity of using the basic rectangular X/Y/Z system. Now, nearly 50 years later, the digital revolution and advances in technology (including AI) make using a 3D datum more feasible than before.
- The Earth-Centered Earth-Fixed (ECEF) rectangular X/Y/Z coordinate system is the foundation of the World Geodetic System 84 (WGS84) defined and maintained by National Geospatial-Intelligence Agency (NGA) [4]. The International Earth Rotation and Reference Service [5] also observes satellite orbits and publishes ECEF coordinates based on the International Terrestrial Reference Frame (ITRF). The WGS84 and the ITRF are computed independently and although the two are not identical, subsequent positioning differences are minimal.

- The defining document for the Global Spatial Data Model (GSDM) [6] was filed with the U.S. Copyright Office in 1997. The GSDM has two components—a functional model that covers the geometry of location and a stochastic model that employs error propagation methods to compute the standard deviation of any derived geometrical quantity (given appropriate covariance matrices are available).

3. Methodology

The approach employed herein is to provide a practical example showing how the GSDM is used to improve the workflow when bridging the gap between field observations and a ground-level 2D survey plat showing directions and distances. Four scenarios will show that horizontal distance distortion is eliminated and that the need for a conformal projection is obviated.

- Scenario 1—The local Point of Beginning (P.O.B.) origin is taken to be the SW Corner of Section 31, T23S-R1E, NM Principal Meridian as shown in **Figure 1**.
- Scenario 2—The P.O.B. origin is taken to be the SE Corner of Section 31, T23S-R1E, NM Principal Meridian.
- Scenario 3—The P.O.B. origin is taken to be NGS HARN station "REILLY" on the NMSU campus, 13 kilometers distant from Section 31.
- Scenario 4—There is no P.O.B. origin. Each vector forming the loop around Section 31 is computed as a geodetic inverse (both forward and back) yielding local directions and distances for each vector.

4. Conventions

- Since the Earth-Centered Earth-Fixed (ECEF) system, X/Y/Z, is "right handed", the east/north/up convention for local right handed coordinates is adopted.
- Mathematically, coordinate differences define a vector ($\Delta X/\Delta Y/\Delta Z$) while a baseline is defined by GPS/GNSS measurements. Although technically different, the terms "baseline" and "vector" are sometimes used interchangeably.
- Coordinate differences, called "delta" (Δ), are computed as Point 2 minus Point 1. Point 1 is the standpoint and called "here". Point 2 is the forepoint and called "there". When reversing direction on a line, Point 2 becomes the new "here" and Point 1 becomes the new "there". Preserving positive/negative signs is important.
- On the globe, longitude is counted from the Greenwich Meridian as 0˚ to 180˚ East (Eastern Hemisphere) and 0˚ to 180˚ West (Western Hemisphere). Although mathematically correct to use west longitude as a negative value, many prefer to use east longitude 0˚ to 360˚.
- The standpoint latitude and longitude are used with a rotation matrix to convert $\Delta X/\Delta Y/\Delta Z$ geocentric coordinate differences to local $\Delta e/\Delta n/\Delta u$ differences (and vice versa). Those local differences are the same as plane surveying coordinates [7].

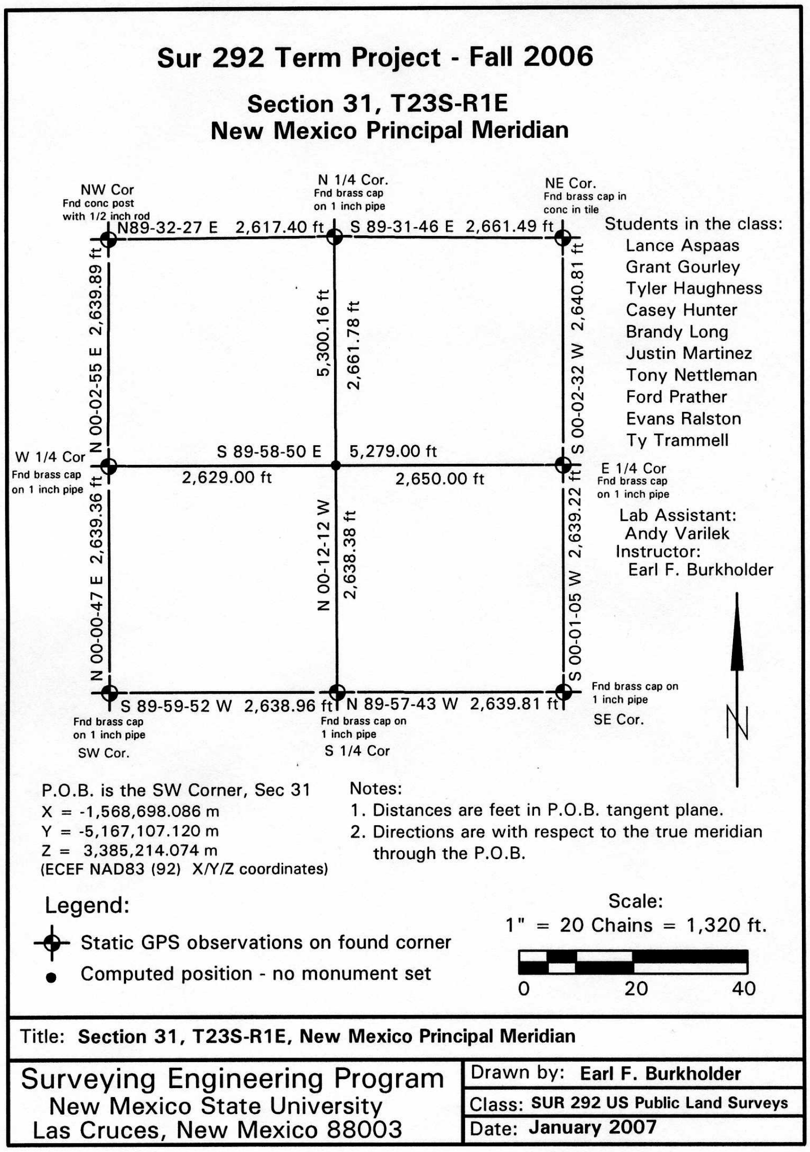

Figure 1. Plat of survey—Section 31, T23S-R1E, New Mexico Principal Meridian.

5. Constraints

Plane surveyors and other spatial data users have a long history deserving of appropriate recognition. Many professional practices flourish under assumptions of local flat-Earth geometry, but the digital revolution drives a larger (global) view. Although acquiring a 3D mindset may require effort, an expanded mindset will enhance a user's ability to connect GSDM coordinates with physical reality—the geometrical equivalent of a digital twin.

- Plumb lines are not parallel. The right triangle component of a slope distance is commonly used as the horizontal distance and is called HD(1) [8]. The tangent plane distance between plumblines is defined as HD(2) and differs slightly from HD(1). Other definitions of HD may depend on the elevation at which the HD is computed.

- Meridians converge at the Poles and are not parallel. Computations in most GISs are simplified because the meridians defined by the underlying map projection (grid north) are parallel. Convergence, the difference between true north and grid north at a point, is also the difference (±180˚) between forward and back azimuths between "here" and "there".
- Meridians and plumblines are both assumed to be parallel in flat-Earth (plane surveying) computations. Map projections used in GISs make it possible to extend the validity of flat-Earth assumptions through the use of grid distances and grid azimuths. Although those procedures have served the user community superbly well, the digital revolution pushes the acceptable limit of flat-Earth assumptions.
- The GSDM accommodates both non-parallel plumb lines and meridians because computations are performed in 3D space—providing a direct connection between actual physical features (ground level) and their GIS representation. The rules of solid geometry embedded in the GSDM offer greater flexibility and give the user more computational choices. Those options (e.g., choosing an appropriate definition of horizontal distance) enable a user to solve a greater range of problems. An esoteric example is computing the shadow height of a blocking mountain at a NEXRAD installation [9] [10].

6. Elements of a GIS

When asked to identify the essential elements of a GIS, Microsoft Copilot listed:

- Hardware
- Software
- Data
- People
- Methods

Acknowledging the benefit of that AI overview, the AI response displays a disturbing absence of human insight. What about the central role of a clearly defined spatial data model which serves as the foundation of the spatial data infrastructure and is fundamental to modern implementation of a GIS?

Change can be difficult and change for the sake of change should be avoided. In some cases, it might be better to stick with an imperfect system that "works" than to incorporate change fostered by disruptive innovation. Given that end users will participate in trade-off discussions, the avowed purpose of this article is to articulate the advantages of improving the spatial data workflow from observation to end use. Two important points: First, a 3D database, utilized by the GSDM, provides a common data exchange place for both generators and users of 3D digital spatial data [11]. Second, using the GSDM as a GIS foundation is compatible with responsible adoption of AI (algorithmic integrity).

7. Applicable Concepts

Geometrical integrity is the foundation of professional practice in engineering, surveying, mapping, and other uses of digital spatial data. Without criticizing map projections and use of separate horizontal and vertical datums, the following issues are associated with the design and implementation of current GISs.

- Mathematical uniqueness for coordinate positions: Different plane coordinate origins help prevent duplication of plane coordinate values zone to zone, including units of meters and feet. Two additional considerations are 1) large coordinate values on a map projection are encountered when covering a large area and 2) Low-Distortion Projections (LDPs) require the use of multiple zones and origins. Careful of location of each LDP origin and assigning appropriate false eastings/northings to each origin makes this a non-problem.
- Distance distortion: Map projections are flat and strictly 2-dimesional. It is impossible to represent a curved distance on the Earth on a flat map without distortion. The solution is to use a Low-Distortion Projection (LDP) in which zone coverage is limited and nominal levels of distortion are of no consequence.
- Conformality: Map projections can be mathematically complex, and cartographers have devised numerous ways of portraying a curved Earth on a flat map. It is critical for spatial data users that an angle on the curved Earth is accurately portrayed on a flat map. A conformal projection based on the Cauchy-Reimann differential equations preserves the angles ground to map. The mathematical complexity of conformal projections can be challenging, but mathematicians and programmers have developed software for converting curvilinear latitude and longitude to rectangular map coordinates and vice versa.
- The GSDM, using a 3D database of ECEF geocentric X/Y/Z coordinates, addresses all three concerns by performing computations in 3D space. A triplet of X/Y/Z geocentric coordinates is unique worldwide. A vector of geocentric coordinate differences ($\Delta X/\Delta Y\Delta Z$) rotated to the local perspective at a standpoint chosen by the user yields local plane coordinate differences ($\Delta e/\Delta n/\Delta u$) "here" to "there". The horizontal distance, HD(1) = sqrt($\Delta e^2 + \Delta n^2$), computed using those local differences, lies in the tangent plane through the designated P.O.B. The azimuth "here" to "there", computed as $\alpha = \arctan(\Delta e/\Delta n)$, with due regard to quadrant, is the true geodetic azimuth of the line with reference to the meridian through the standpoint [12]. There is no distortion of the horizontal distance and GSDM azimuth differences to multiple forepoints yield the same angle as observed on the ground. Preservation of the angles is demonstrated in the examples cited in this paper and the complexity of a conformal projection for directions is avoided. The rotation matrix used to convert between geocentric and local differences is derived in Appendix A of [13] and [14] and shown in [7].
- The following links document the rigor of GSDM distances and azimuths.

- Horizontal: http://www.globalcogo.com/HD-Options.pdf [8].
- Azimuths: http://www.globalcogo.com/3DGPSAZ.pdf [12].

8. Project

The scenarios described in this article are part of a project completed nearly 20 years ago [15]. Primary computations are based on ECEF control points and GPS baselines. Latitude, longitude, and ellipsoid height are computed by a standard least squares adjustment. Distances are in meters except that (in deference to USPLSS convention), distances on the 2007 plat are shown in U.S. Survey Feet. Metric distances are used in this paper.

The NMSU class project, GPS observations, network adjustment, and plat, is documented in [15]. Note that the stations and coordinates, listed in **Figure 2**, represent a "hand-over" by the generators of 3D digital spatial data (NMSU SUR 292 surveying students) for the benefit of subsequent spatial data users (current readers) [11].

	ECEF Frame			Local Frame		
CRUCESAIR	X =	-1,571,430.6720 m	fixed	Lat.	32° 16′ 54.″63123 N	derived
(HARN PT)	Y =	-5,164,782.3120 m	fixed	Long.	106° 55′ 22.″24784 W	derived
	Z =	3,387,603.1880 m	fixed	El Hgt	h = 1,326.250 m	derived
REILLY	X =	-1,556,177.6150 m	fixed	Lat.	32° 16′ 55.92906 N	derived
(HARN PT)	Y =	-5,169,235.3190 m	fixed	Long.	106° 45′ 15.16070 W	derived
	Z =	3,387,551.7090 m	fixed	El Hgt	h = 1,166.570 m	derived
NW Cor 31:	X =	-1,568,446.9652 m	+/- 0.0033 m	Lat.	32° 16′ 16.51587 N	+/- 0.0054 m
	Y =	-5,166,282.9266 m	+/- 0.0077 m	Long.	106° 53′ 16.50858 W	+/- 0.0039 m
	Z =	3,386,573.0861 m	+/- 0.0044 m	El Hgt	h = 1,256.511 m	+/- 0.0067 m
NE Cor 31:	X =	-1,566,906.8273 m	+/- 0.0034 m	Lat.	32° 16′ 16.50308 N	+/- 0.0057 m
	Y =	-5,166,748.4577 m	+/- 0.0080 m	Long.	106° 52′ 15.04095 W	+/- 0.0040 m
	Z =	3,386,571.5363 m	+/- 0.0046 m	El Hgt	h = 1,254.233 m	+/- 0.0070 m
SW Cor 31:	X =	-1,568,698.0864 m	+/- 0.0035 m	Lat.	32° 15′ 24.28753 N	+/- 0.0058 m
	Y =	-5,167,107.1198 m	+/- 0.0083 m	Long.	106° 53′ 16.54155 W	+/- 0.0041 m
	Z =	3,385,214.0743 m	+/- 0.0047 m	El Hgt	h = 1,259.609 m	+/- 0.0072 m
SE Cor 31:	X =	-1,567,157.4899 m	+/- 0.0035 m	Lat.	32° 15′ 24.26696 N	+/- 0.0058 m
	Y =	-5,167,571.1861 m	+/- 0.0081 m	Long.	106° 52′ 15.08320 W	+/- 0.0041 m
	Z =	3,385,211.2732 m	+/- 0.0047 m	El Hgt	h = 1,255.365 m	+/- 0.0071 m
N ¼ Cor 31:	X =	-1,567,682.4363 m	+/- 0.0036 m	Lat.	32° 16′ 16.72241 N	+/- 0.0058 m
	Y =	-5,166,510.8119 m	+/- 0.0080 m	Long.	106° 52′46.03144 W	+/- 0.0042 m
	Z =	3,386,578.0990 m	+/- 0.0048 m	El Hgt	h = 1,255.823 m	+/- 0.0070 m
W ¼ Cor 31:	X =	-1,568,572.7788 m	+/- 0.0035 m	Lat.	32° 15′ 50.39908 N	+/- 0.0058 m
	Y =	-5,166,694.9985 m	+/- 0.0080 m	Long.	106° 53′ 16.53459 W	+/- 0.0041 m
	Z =	3,385,893.5160 m	+/- 0.0048 m	El Hgt	h = 1,258.017 m	+/- 0.0070 m
S ¼ Cor 31:	X =	-1,567,928.0513 m	+/- 0.0038 m	Lat.	32° 15′ 24.28747 N	+/- 0.0060 m
	Y =	-5,167,339.5732 m	+/- 0.0083 m	Long.	106° 52′ 45.81734 W	+/- 0.0044 m
	Z =	3,385,213.3104 m	+/- 0.0050 m	El Hgt	h = 1,258.181 m	+/- 0.0073 m
E ¼ Cor 31:	X =	-1,567,032.6554 m	+/- 0.0038 m	Lat.	32° 15′ 50.37719 N	+/- 0.0059 m
	Y =	-5,167,160.8706 m	+/- 0.0082 m	Long.	106° 52′ 15.06861 W	+/- 0.0043 m
	Z =	3,385,891.8435 m	+/- 0.0048 m	El Hgt	h = 1,255.952 m	+/- 0.0072 m

Figure 2. Project control points and section corner coordinates.

9. Computations

The 2007 paper [15] includes a final plat (**Figure 1**) based on the 3D GPS survey. The 2D plat was computed assuming a local P.O.B. at the SW Corner of Section 31 and the local eastings and northings for each point are computed with respect to that P.O.B. The bearings and distances around the section lie in the tangent plane through the P.O.B. The distances are local ground level, and the bearings are with respect to the true meridian through the P.O.B. The sum of the interior angles adds up to a multiple of 180˚ and there are no issues about it being a conformal map. Conceptually, the details are identical to plane surveying practices traditionally employed by most surveyors. All four scenarios discussed herein are based on the same ECEF coordinate values listed in Figure 2.

10. Particulars

The rotation matrix, described previously, is used frequently with the GSDM. The following printout shows an inverse between the SW Corner of Section 31 and the SE Corner of the same section. Several logical points are:

- The project data shown in Figure 2 include both coordinates and standard deviations. Including standard deviations is beyond the scope of this paper.
- Figure 3 is a portion of a BURKORD™ printout showing inverses, forward and back, between the SW Corner and the SE Corner of Section 31.
- Except for a change in sign, the ΔX/ΔY/ΔZ values are identical. However, because the standpoint meridians are not parallel and because there are two slightly different tangent planes, the Δe/Δn/Δu values are somewhat different between forward and back computations. But, regardless of forward or reverse, the 3D spatial distances are identical, and the horizontal distances are nearly the same.

$$3D = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} = \sqrt{\Delta e^2 + \Delta n^2 + \Delta u^2}\ \text{fwd} = \sqrt{\Delta e^2 + \Delta n^2 + \Delta u^2}\ \text{rev} \quad (1.0)$$

- The difference between forward and back azimuths (180˚ + 32.8 seconds) is the convergence of the meridians between the SW Corner and the SE Corner of Section 31. That same convergence shows up in the difference of bearings (azimuths) in Scenarios 1 and 2.

```
SW Cor Sec 31
X =  -1568698.0860  m            LAT (N+S-)     32 15 24.287517
Y =  -5167107.1200  m            LON (E+W-) -106 53 16.541530
Z =   3385214.0740  m            EL HGT            1259.6089 m

DELTA X/Y/Z                      1540.5960 m   -464.0660 m    -2.8010 m
DELTA E/N/U                      1608.9690 m     -0.5055 m    -4.4471 m     (Forward)
LOCAL PLANE INV: DIST =          1608.9690 m            N AZI. =  90  1  4.81

SE Cor Sec 31
X =  -1567157.4900 m             LAT (N+S-)     32 15 24.266956
Y =  -5167571.1860 m             LON (E+W-) -106 52 15.083204
Z =   3385211.2730 m             EL HGT             1255.3645 m

DELTA X/Y/Z                      -1540.5960 m    464.0660 m    2.8010 m
DELTA E/N/U WITH SIGMAS          -1608.9699 m      0.7614 m    4.0417 m     (Reverse)
LOCAL PLANE INV: DIST =          1608.9701 m          N AZI. = 270  1 37.61

SW Cor Sec 31
X =  -1568698.0860 m             LAT (N+S-)     32 15 24.287517
Y =  -5167107.1200 m             LON (E+W-) -106 53 16.541530
Z =   3385214.0740  m            EL HGT             1259.6089 m
```

Figure 3. BURKORDTM printout of directions and distances—SW and SE Corners, Sec 31.

11. Scenarios

11.1. Scenario 1

The bearings and distances in the 2007 paper [15] are based on the ECEF coordinate values of the section corners. The P.O.B. was chosen to be the SW Corner of Section 31 and the rotation matrix was used to compute local components from the SW Corner to each of the other section corners—see Figure 4. The plane surveying bearings and distances on the plat were computed from eastings and northings computed with respect to the chosen P.O.B. Although the "up" component is part of the rotation computation, "up" is not used here.

Corner	East		North		Up	
SW Cor.	0.0000	m	0.0000	m	0.0000	m
W 1/4	0.1814	m	804.4781	m	-1.6432	m
NW Cor.	0.8628	m	1609.117	m	-3.3014	m
N 1/4	798.6221	m	1615.512	m	-4.0412	m
NE Cor.	1609.8191	m	1608.85	m	-5.7828	m
E 1/4	1609.2237	m	803.9305	m	-3.9101	m
SE Cor.	1608.969	m	-0.5055	m	-4.4471	m
S 1/4	804.3548	m	0.0302	m	-1.4794	m

Point		Easting From P.O. B.		Northing From P.O.B.			Horizontal Distance		Azimuth/Bearing D	M	S	Interior Angles D	M	S
SW Cor.		0.0000	m	0.0000	m									
	Δ =	0.1814	m	804.4781	m	HD =	804.478	m	0	0	46.51			
W 1/4		0.1814	m	804.4781	m							179	57	51.84
	Δ =	0.6814	m	804.6390	m	HD =	804.639	m	0	2	54.67			
NW Cor.		0.8628	m	1609.1171	m							90	30	28.05
	Δ =	797.7593	m	6.3948	m	HD =	797.785	m	89	32	26.63			
N 1/4		798.6221	m	1615.5119	m							179	4	12.81
	Δ =	811.1970	m	-6.6616	m	HD =	811.224	m	90	28	13.82			
NE Cor.		1609.8191	m	1608.8503	m							90	25	41.25
	Δ =	-0.5954	m	-804.9198	m	HD =	804.920	m	180	2	32.57			
E 1/4		1609.2237	m	803.9305	m							180	1	27.27
	Δ =	-0.2547	m	-804.4360	m	HD =	804.436	m	180	1	5.31			
SE Cor.		1608.969	m	-0.5055	m							89	58	47.98
	Δ =	-804.6142	m	0.5357	m	HD =	804.614	m	270	2	17.33			
S 1/4		804.3548	m	0.0302	m							180	2	25.07
	Δ =	-804.3548	m	-0.0302	m	HD =	804.355	m	269	59	52.26			
SW Cor.		0.0000	m	0.0000	m							89	59	5.75
	Δ =	0.1814	m	804.4781	m	HD =	804.478	m	0	0	46.51			
W 1/4		0.1814	m	804.4781	m		Sum of Interior Angles =					1080	0	0.02
Computations by Earl F. Burkholder, January 2, 2026														

Figure 4. Bearings, distances, and angles based on P.O.B. at SW Corner, Section 31.

11.2. Scenario 2

Scenario 2 is the same as Scenario 1 except that the P.O.B. origin is at the SE Corner of Section 31. The tangent plane for the data in Figure 5 is slightly different than the tangent plane in Scenario 1, but the local distances are essentially the same. The bearings shown in Scenario 1 and Scenario 2 differ by the convergence between the SW Corner and the SE Corner. The interior angles at each corner are the same and the sum of interior angles adds up to a multiple of 180˚.

Note that the bearings in Scenario 2 are different from those in Scenario 1 by

32.8 seconds of arc, the same as the convergence between the two P.O.B.s.

11.3. Scenario 3

Scenario 3 is the same as Scenario 1 except that the chosen P.O.B. is HARN station REILLY located 13 kilometers (8 mi.) away on the NMSU campus. Computations are based on data in Figure 6. The local distances on the plat are the same as in Scenario 1 and the bearings are different due to the convergence between REILLY and the SW Corner of Section 31. Interior angles are unchanged.

11.4. Scenario 4

Scenario 4 assumes that the standpoint of each vector is the origin for the "forward" computation to the forepoint. The "back" computation reverses the computation by using the previous standpoint as "here" while the previous forepoint is taken to be "here". The difference (±180˚) in forward and back azimuths represents the convergence of the meridians between those two points. Results in Figure 7 are based on the data in Figure 2. There is little or no difference between the distances forward and back. But the forward and reverse distances could be quite different if standpoint and forepoint are at significantly different heights [8].

Corner	Easting		Northing		Up	
SW Cor.	-1,608.9699	m	0.7614	m	4.0417	m
W 1/4	-1,608.6602	m	805.2395	m	2.3985	m
NW Cor.	-1,607.8504	m	1,609.8783	m	0.7405	m
N 1/4	-810.0900	m	1,616.1463	m	0.2016	m
NE Cor.	1.1064	m	1,609.3557	m	-1.3356	m
E 1/4	0.3825	m	804.4360	m	0.5370	m
SE Cor.	0.0000	m	0.0000	m	0.0000	m
S 1/4	-804.6148	m	0.6637	m	2.7650	m

Point		Easting From P.O. B.		Northing From P.O.B.			Horizontal Distance		Azimuth/Bearing D	M	S	Interior Angles D	M	S
SW Cor.		-1,608.9699	m	0.7614	m									
	Δ =	0.3097	m	804.4781	m	HD =	804.478	m	0	1	19.41			
W 1/4		-1,608.6602	m	805.2395	m							179	57	51.82
	Δ =	0.8098	m	804.6388	m	HD =	804.639	m	0	3	27.59			
NW Cor.		-1,607.8504	m	1,609.8783	m							90	30	28.18
	Δ =	797.7604	m	6.2680	m	HD =	797.785	m	89	32	59.41			
N 1/4		-810.0900	m	1,616.1463	m							179	4	12.79
	Δ =	811.1964	m	-6.7906	m	HD =	811.225	m	90	28	46.62			
NE Cor.		1.1064	m	1,609.3557	m							90	25	41.12
	Δ =	-0.7239	m	-804.9197	m	HD =	804.920	m	180	3	5.50			
E 1/4		0.3825	m	804.4360	m							180	1	27.43
	Δ =	-0.3825	m	-804.4360	m	HD =	804.436	m	180	1	38.08			
SE Cor.		0.0000	m	0.0000	m							89	58	47.94
	Δ =	-804.6148	m	0.6637	m	HD =	804.615	m	270	2	50.14			
S 1/4		-804.6148	m	0.6637	m							180	2	25.09
	Δ =	-804.3551	m	0.0977	m	HD =	804.355	m	270	0	25.05			
SW Cor.		-1,608.9699	m	0.7614	m							89	59	5.65
	Δ =	0.3097	m	804.4781	m	HD =	804.478	m	0	1	19.41			
W 1/4		-1,608.6602	m	805.2395	m		Sum of Interior Angles =					1080	0	0.02
Computations by Earl F. Burkholder, January 2, 2026														

Figure 5. Bearings, distances, and angles based on P.O.B. at SE Corner, Section 31.

Corner	Easting	Northing	Up
SW Cor.	-12,602.4684 m	-2,815.5576 m	79.9788 m
W 1/4	-12,601.2810 m	-2,011.0802 m	78.6943 m
NW Cor.	-12,599.5947 m	-1,206.4415 m	77.3960 m
N 1/4	-11,801.8282 m	-1,201.0410 m	78.2330 m
NE Cor.	-10,990.6383 m	-1,208.7126 m	78.0890 m
E 1/4	-10,992.2401 m	-2,013.6316 m	79.6019 m
SE Cor.	-10,993.4952 m	-2,818.0668 m	78.7060 m
S 1/4	-11,798.1126 m	-2,816.5294 m	80.0864 m

		Easting	Northing		Horizontal	Azimuth/Bearing			Interior Angles		
Point		From P.O. B.	From P.O.B.		Distance	D	M	S	D	M	S
SW Cor.		-12,602.4684 m	-2,815.5576 m								
	Δ =	1.1874 m	804.4774 m	HD =	804.478 m	0	5	4.44			
W 1/4		-12,601.2810 m	-2,011.0802 m						179	57	52.17
	Δ =	1.6863 m	804.6387 m	HD =	804.640 m	0	7	12.27			
NW Cor.		-12,599.5947 m	-1,206.4415 m						90	30	28.57
	Δ =	797.7665 m	5.4005 m	HD =	797.785 m	89	36	43.71			
N 1/4		-11,801.8282 m	-1,201.0410 m						179	4	13.07
	Δ =	811.1899 m	-7.6716 m	HD =	811.226 m	90	32	30.63			
NE Cor.		-10,990.6383 m	-1,208.7126 m						90	25	40.16
	Δ =	-1.6018 m	-804.9190 m	HD =	804.921 m	180	6	50.47			
E 1/4		-10,992.2401 m	-2,013.6316 m						180	1	28.65
	Δ =	-1.2551 m	-804.4352 m	HD =	804.436 m	180	5	21.82			
SE Cor.		-10,993.4952 m	-2,818.0668 m						89	58	47.71
	Δ =	-804.6174 m	1.5374 m	HD =	804.619 m	270	6	34.11			
S 1/4		-11,798.1126 m	-2,816.5294 m						180	2	24.91
	Δ =	-804.3558 m	0.9718 m	HD =	804.356 m	270	4	9.20			
SW Cor.		-12,602.4684 m	-2,815.5576 m						89	59	4.76
	Δ =	1.1874 m	804.4774 m	HD =	804.478 m	0	5	4.44			
W 1/4		-12,601.2810 m	-2,011.0802 m		Sum of Interior Angles =				1080	0	0.00
Computations by Earl F. Burkholder, January 2, 2026											

Figure 6. Bearings, distances, and angles based on the P.O.B. at HARN station REILLY.

	Point to Point		Geocentric Vector ΔX =	ΔY =	ΔZ =	Local Vector Δe =	Δn =	Δu =	HD(1) Distance	True 3D Azimuth D	M	S
Fwd	SW Cor.	W 1/4	125.3076 m	412.1213 m	679.4417 m	0.1814 m	804.4781 m	-1.6432 m	804.478 m	0	0	46.52
Rev	W 1/4	SW Cor.	-125.3076 m	-412.1213 m	-679.4417 m	-0.1814 m	-804.4783 m	1.5414 m	804.478 m	180	0	46.52
									Interior angle at W 1/4 =	179	57	51.85
Fwd	W 1/4	NW Cor.	125.8136 m	412.0719 m	679.5701 m	0.6814 m	804.6392 m	-1.5563 m	804.639 m	0	2	54.67
Rev	NW Cor.	W 1/4	-125.8136 m	-412.0719 m	-679.5701 m	-0.6814 m	-804.6393 m	1.4544 m	804.640 m	180	2	54.68
									Interior angle at NW Cor. =	90	30	28.09
Fwd	NW Cor.	NE 1/4	764.5289 m	-227.8853 m	5.0129 m	797.7593 m	6.3950 m	-7.7382 m	797.785 m	89	32	26.59
Rev	NE 1/4	NW Cor.	-764.5289 m	227.8853 m	-5.0129 m	-797.7599 m	-6.3320 m	0.6385 m	797.785 m	269	32	42.86
									Interior angle at N 1/4 =	179	4	12.86
Fwd	N 1/4	NE Cor.	775.6090 m	-237.6458 m	-6.5627 m	811.1964 m	-6.7252 m	-1.6418 m	811.224 m	90	28	30.00
Rev	NE Cor.	N 1/4	-775.6090 m	237.6458 m	6.5627 m	-811.1964 m	6.7903 m	1.5388 m	811.225 m	270	28	46.55
									Interior angle at NE Cor. =	90	25	41.03
Fwd	NE Cor.	E 1/4	-125.8281 m	-412.4129 m	-679.6928 m	-0.7240 m	-804.9201 m	1.6688 m	804.920 m	180	3	5.52
Rev	E 1/4	NE Cor.	125.8281 m	412.4129 m	679.6928 m	0.7239 m	804.9199 m	-1.7707 m	804.920 m	0	3	5.51
									Interior angle at E 1/4 =	180	1	27.42
Fwd	E 1/4	SE Cor.	-124.8345 m	-410.3155 m	-680.5703 m	-0.03825 m	-804.4359 m	-0.6388 m	804.436 m	180	1	38.09
Rev	SE Cor.	E 1/4	124.8345 m	410.3155 m	680.5703 m	0.3825 m	804.4360 m	0.5370 m	804.436 m	0	1	38.08
									Interior angle at SE Cor. =	89	58	47.94
Fwd	SE Cor.	S 1/4	-770.5601 m	231.6161 m	2.0368 m	-804.6148 m	0.6637 m	2.765 m	804.615 m	270	2	50.14
Rev	S 1/4	SE Cor.	770.5601 m	-231.6161 m	-2.0368 m	804.6144 m	-0.5997 m	-2.8664 m	804.615 m	90	2	33.74
									Interior angle at S 1/4 =	180	2	25.10
Fwd	S 1/4	SW Cor.	-770.0364 m	232.4502 m	0.7643 m	-804.3550 m	0.0337 m	1.3781 m	804.355 m	270	0	8.64
Rev	SW Cor.	S 1/4	770.0364 m	-232.4502 m	-0.7643 m	804.3548 m	0.0302 m	-1.4794 m	804.355 m	89	59	52.25
									Interior angle at SW Cor. =	89	59	5.73
Fwd	SW Cor.	W 1/4	125.3076 m	412.1213 m	679.4417 m	0.1814 m	804.4781 m	-1.6432 m	804.478 m	0	0	46.52
Rev	W 1/4	SW Cor.	-125.3076 m	-412.1213 m	-679.4417 m	-0.1814 m	-804.4783 m	1.5414 m	804.478 m	180	0	46.52
									Sum of Interior Angles =	1080	0	0.02
	Computations by Earl F. Burkholder, January 4, 2026											

Figure 7. Forward/revere computations for each baseline and tabulation of interior angles.

12. Conclusions

A word of caution—the GSDM can be easily misused. As with careless use of matches or manipulating weights in a least squares adjustment to get an acceptable answer, the GSDM can be misused (unwittingly or deviously) with little chance of being detected. In particular, horizontal distance varies with elevation. A user can easily traverse to any height at the P.O.B. by computing X/Y/Z coordinates for an "imaginary" height. Accordingly, subsequent computations referred to that P.O.B. will be affected [8]. The GSDM provides many tools for the user, but it also requires accountability for proper use.

Because meridians are not parallel, the bearing of each line is different in each scenario. However, the computed interior angles are identical in each case, and the computed local horizontal distances are the same (within a small tolerance).

12.1. Takeaways Include but Are Not Limited to

- Horizontal distances as measured in the field are portrayed without distortion on the map. Computed from four different scenarios, the distances shown on the map of Section 31 are the same.
- Although bearings in the examples differ because meridians are not parallel, the interior angles in Section 31, as computed from all four examples, are the same.
- The GSDM obviates the need for a conformal projection. LDP zones, false eastings and northings, scale factors, elevation factors, and complicated transformation equations are not needed.
- The GSDM is seamless. Two adjoining survey projects fit together nicely with the exception that, if different P.O.B.s are used, the bearing differences between the two projects are dictated by the convergence between the P.O.B.s.
- Local horizontal distances are compatible unless there is a significant difference in the ellipse height of the tangent planes of the two P.O.B.s [8].

12.2. Additional Considerations Include

- The GSDM is a three-dimensional model for spatial data, but time is readily accommodated as the 4th dimension.
- The third dimension is not discussed here. Ongoing research addresses the impact of gravity on heights. Those impacts need to be discussed further.
- Although standard deviations are included in the data (**Figure 1**), this paper does not include error propagation. But the stochastic portion of the GSDM handles spatial data accuracy very well. Applicable references include [16] and [17].
- The GSDM is based on ECEF coordinates referenced to a named datum. The National Geodetic Survey (NGS) provides software for moving X/Y/Z coordinate values from one datum to another—https://geodesy.noaa.gov/NCAT/. For example, the plat in **Figure 2** is based on NAD 83 (1992) while the current values for control stations REILLY and CRUCESAIR are based on NAD 83 (2011).
- The GSDM contains tools that can be used to explore limits of "flat Earth"

practices, even laying out parallels of latitude—see Example 12 in reference [14].

- In some cases, too many significant digits are shown in the 4 scenarios in an effort to control round-off. The agreement of results between scenarios is not exact. Neither are the original data exact. Error propagation of the least squares results [15] can ultimately provide a reliable standard deviation of any derived quantity. Propagation of the standard deviations shown in **Figure 2**, and included in [17], can reveal the integrity of results.

Acknowledgements

Input from the Editor and anonymous reviewers is greatly appreciated. Mr. Scott Farnham, PE, PS, former City Surveyor for Las Cruces, NM, also shared insights that were used to improve this article.

Conflicts of Interest

Subject to intellectual property issues, the author declares no conflicts of interest regarding publication of this paper.

References

[1] Burkholder, E.F. (2026) Evolution of GIS: Learning from the Past—Looking to the Future. *Journal of Geographic Information System*, **18**, 1-11. https://doi.org/10.4236/jgis.2026.181001

[2] Bomford, G. (1971) Geodesy. 3rd Edition, Oxford University Press.

[3] Moritz, H. (1978) Definition of a Geodetic Datum. *Proceedings 2nd International Symposium on Problems Related to the Redefinition of North American Geodetic Networks*, Arlington, 24-28 April 1978, 64, 72. https://archive.org/details/proceedingsofsec00inte

[4] National Geospatial-Intelligence Agency (2014) Department of Defense World Geodetic System of 1984: Its Definition and Relationship with Local Geodetic Systems, "NGA.STND.0036_1.0.0_WGS84". NGA, Office of Geomatics. https://search.yahoo.com/yhs/search?hspart=trp&hsimp=yhs-018&grd=1&type=Y143_F163_225899_091823&p=NGA.STND.0036_1.0.0_WGS84

[5] International Terrestrial Reference Frame (ITRF), International Earth Rotation and Reference System Service. https://www.iers.org/IERS/EN/DataProducts/ITRF/itrf/

[6] Burkholder, E.F. (1997) Definition and Description of a Global Spatial Data Model (GSDM). Filed with the U.S. Copyright Office. http://www.globalcogo.com/gsdmdefn.pdf

[7] Burkholder, E.F. (2025) Animation—Using Rotation Matrix to Convert GPS Baselines to Plane Surveying Components. http://www.globalcogo.com/XYZ-to-enu.mp4

[8] Burkholder, E.F. (2018) Horizontal Distance Options Supported by the 3D Global Spatial Data Model (GSDM). http://www.globalcogo.com/HD-Options.pdf

[9] Schurian, D., Hodges, J. and Burkholder, E. (1997) 3D Analysis: Siting a NEXRAD Weather Radar System. *Professional Surveyor Magazine*, **17**, 20, 21, 22, 24, 28. http://www.globalcogo.com/NEXRAD.pdf

[10] Burkholder, E.F. (2015) Profile View of Shadow Height for NEXRAD Facility. http://www.globalcogo.com/shadow-height-profile.pdf

[11] Burkholder, E.F. (2025) Facilitating Exchange between Spatial Data Generators and Users. http://www.tru3d.xyz/common.pdf

[12] Burkholder, E.F. (1997) Three-Dimensional Azimuth of GPS Vector. *Journal of Surveying Engineering*, **123**, 139-146. https://doi.org/10.1061/(asce)0733-9453(1997)123:4(139)

[13] Burkholder, E.F. (2008) The 3D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure. CRC Press.

[14] Burkholder, E.F. (2018) The 3D Global Spatial Data Model: Principles and Applications. 2nd Edition, CRC Press.

[15] Burkholder, E.F. (2007) From 3D GPS Data to a 2D Plat. NMSU Surveying Class Project. http://www.globalcogo.com/3DGPS.pdf

[16] Burkholder, E.F. (1999) Spatial Data Accuracy as Defined by the GSDM. *Journal of Surveying and Land Information Systems*, **59**, 26-30. http://www.globalcogo.com/accuracy.pdf

[17] Burkholder, E.F. (2017) Concepts of Spatial Data Accuracy Need Our Attention. *Surveyors and Geomatics Educators' Society Conference*, Corvallis, 30 July-3 August 2017. http://www.globalcogo.com/EFB-SaGES-ALTA-NSPS.pdf