The Global Spatial Data Model (GSDM)

Earl F. Burkholder, PS, PE
Surveying Engineering Department - 3SUR
New Mexico State University - Las Cruces, NM 88003

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Abstract

Spatial data are 3-dimensional (3-D) and modern measurement systems collect data in a 3-D environment. Computer data bases store 3-D digital spatial data. Human perception of spatial relationships is primarily visual and, due to gravity, our natural reference for spatial experience is horizontal (2-D) and vertical (1-D). Various models are used to establish a conceptual connection between the measurements, digital spatial data, and its representation - data visualization. Digital spatial data are also used to make analog products such as maps, charts, and other hardcopy diagrams. The point is, once spatial data are put into digital form, they can be manipulated at the whim of the user. To preserve the integrity and value of spatial data, there should be a common storage format and the data manipulation processes should be well-defined, unique, bi-directional, and three-dimensional. Of course, the challenge is to identify a common format for 3-D data which is at the same time simple, rigorous, and global. The data storage format must also accommodate reliable statistical measures of spatial data accuracy.

The global spatial data model (GSDM) described in this presentation is a collection of concepts and procedures which can be used to collect, organize, store, process, and manipulate 3-D spatial data. The GSDM uses one set of solid geometry equations which are equally applicable around the world. This simple standard preserves global interoperability and each discipline, agency, corporation, or individual spatial data user is free to implement any derivative use or application.

The GSDM includes both a functional model and a stochastic model. The functional model encompasses the geometry of spatial relationships and the stochastic model defines the process for establishing, tracking, and reporting the accuracy of spatial data using existing standard mathematical procedures.

Introduction

An appropriate introduction to the global spatial data model (GSDM) might be to list several challenges facing geospatial data users. According to Vice President Al Gore (1998) in a speech titled, The Digital Earth: Understanding our planet in the 21st century, "the hard part of taking advantage of this flood of geospatial information will be making sense of it - turning raw data into understandable information." The following challenges all come under the umbrella of Gore's statement, but are listed separately for purposes of this discussion. Challenges for spatial data users include:

1. Handling vast amounts of 3-dimensional (3-D) digital spatial data efficiently.

2. Describing spatial data accuracy without ambiguity.

3. Finding the best (appropriate) combination of tools, talents, and resources to accomplish the task at hand.

The third challenge is very open ended and relies heavily on the judgment of the user but the first two challenges are addressed specifically by the GSDM and supported by an underlying BURKORD® database (see www.zianet.com/globalcogo). The functional model portion of the GSDM includes geometrical equations which permit each user to work with local rectangular (flat earth) coordinate differences while preserving true geometrical integrity on a global scale. The stochastic model portion of the GSDM includes rigorous error propagation procedures which accommodate input of measurement uncertainties and provide output of standard deviations for each 3-D coordinate position and/or other derived quantities. It has been said, "No job is difficult if you have the right tools." The goal of this paper is to examine features of the GSDM with the idea of finding better tools for handling digital spatial data. If the GSDM is an appropriate tool, and if it can be used beneficially by various disciplines, then the larger issue is becoming more familiar with the fundamental concepts, using and building on those concepts, and sharing that knowledge with others. As Al Gore concluded in his speech, "Working together, we can help solve many of the most pressing problems facing our society..."

Definition of the Global Spatial Data Model (GSDM)

The GSDM, formally defined in (Burkholder 1997), is a collection of existing mathematical concepts and procedures which can be used to manage spatial data both locally and globally. It consists of a functional model which describes the geometrical relationships and a stochastic model which describes the probabilistic characteristics--statistical qualities--of spatial data. The functional part of the model includes equations of geometrical geodesy and rules of vector algebra (solid geometry) as related to various coordinate systems, see Figure 1, Diagram Showing Relationship of Coordinate Systems. The primary coordinate system

The BURKORD™ 3-D Diagram

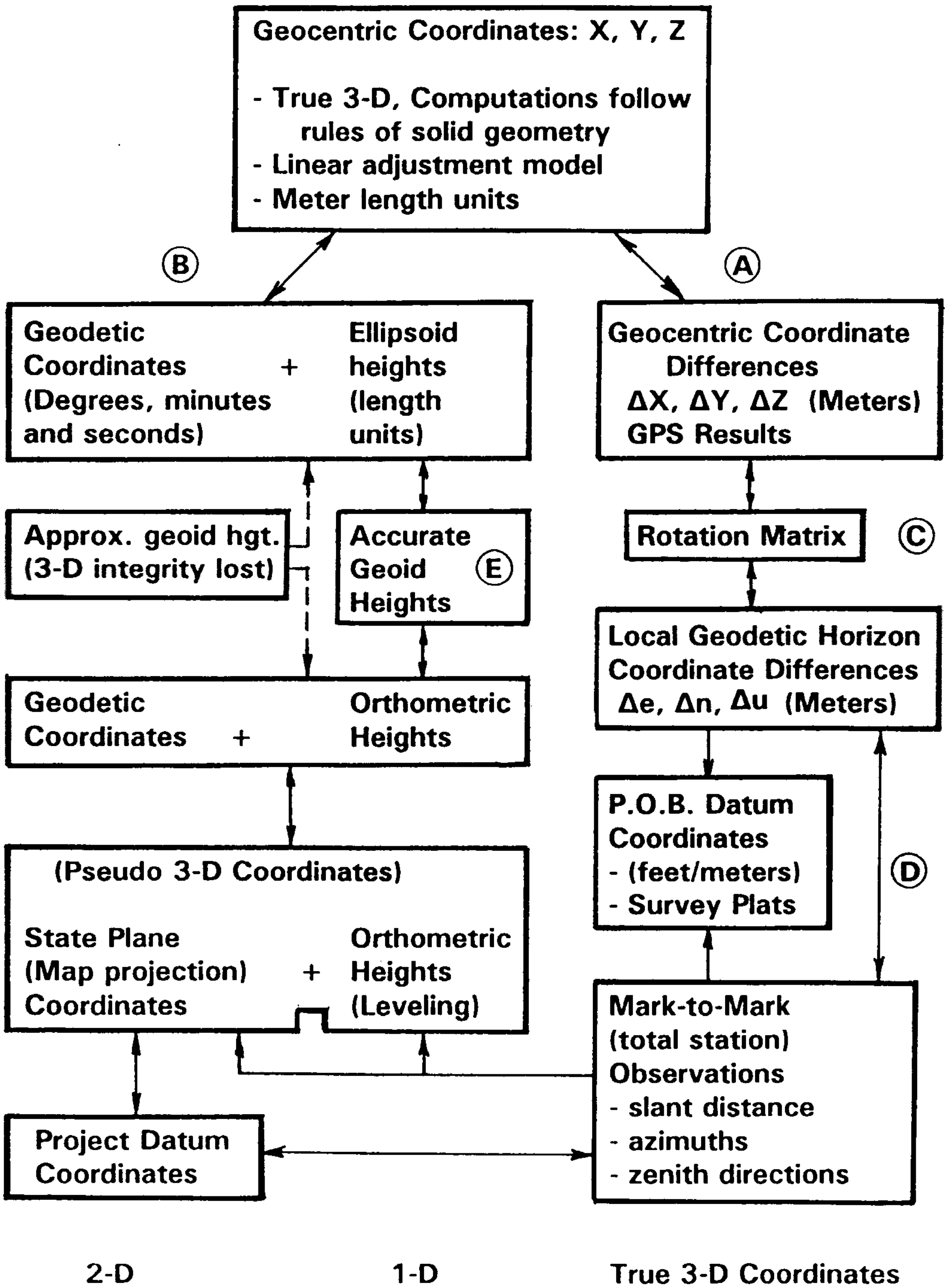

Figure 1 Diagram Showing Relationship of Coordinate Systems

used by the GSDM is the earth-centered earth-fixed (ECEF) geocentric X/Y/Z coordinate system as defined by the Department of Defense (DMA 1991). The GSDM is intended to be consistent with the 3-D Geodetic Model described by Leick (1995) with the following exception; the GSDM, being strictly spatial, does not include gravity measurements, but presumes gravity affects are accommodated before data are entered into the spatial model.

The stochastic model component of the GSDM uses fundamental error propagation concepts as described in Chapter 4 of Mikhail (1976) and Chapter 5 of Wolf/Ghilani (1997). The GSDM stores stochastic information in the variance/covariance matrix associated with each point defined by ECEF coordinates and in the correlation between point-pairs. The local perspective (e/n/u) covariance values and standard deviations need not be stored but are computed upon demand from the geocentric values. The accuracy defined by each point covariance matrix, whether geocentric or local, is called **datum accuracy**. A BURKORD® 3-D database accommodates storage of both the geocentric covariance values for each point and the point-pair correlation. That capability supports and allows one to exploit the rigorous mathematical definitions of **local accuracy, network accuracy,** and **P.O.B. accuracy** when computing the position of one point with respect to another (Burkholder 1999).

Figure 2 is a diagram of the GSDM listing the core concepts surrounded by various disciplines which, to one degree or another, use geographic information systems based upon the National Spatial Data Infrastructure (NSDI) as defined by President Clinton (1994) in Executive Order 12906 signed April 11, 1994. The GSDM fully supports the NSDI and is compatible with details of that Executive Order.

Features of the Global Spatial Data Model (GSDM)

It is not possible or feasible to describe all the features of the GSDM here but several of the more prominent features are:

1. The GSDM uses existing standard mathematical equations of solid geometry and vector algebra for defining the location of a point and for manipulating spatial data. Many complicated geometrical geodesy equations, needed when working with the mathematical ellipsoid model, can be avoided. Instead, using a rotation matrix, the GSDM provides a way to view any set of global X/Y/Z points in terms of local "flat earth" coordinate differences. Additionally, no geometrical integrity is lost (due to the model) and traditional coordinate systems (latitude/longitude) can still be used as or if desired.

2. The GSDM utilizes rigorous error propagation concepts in all three dimensions and provides a standard set of tools which can be used by various disciplines to describe spatial data accuracy with statistical reliability. Meta data are still important but, in many cases, standard deviations are more efficient because they provide a numerical filter for categorizing the accuracy of each point; horizontal, vertical, or both.

Global Spatial Data Model - GSDM

(A Universal 3-D Model for Spatial Data)

The Global Spatial Data Model provides a simple, universal 3-dimensional mathematical foundation for the National Spatial Data Infrastructure (NSDI) which supports Geographic Information System (GIS) database applications in disciplines such as:

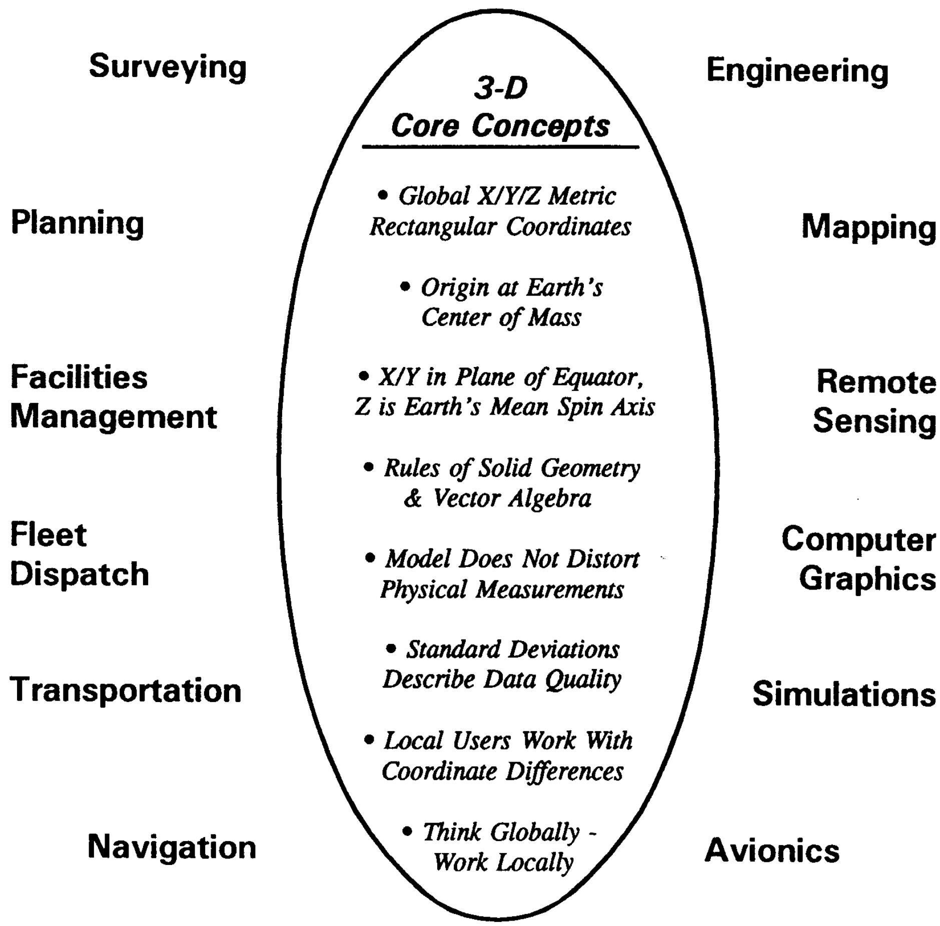

Figure 2 The Global Spatial Data Model (GSDM)

Circleville, Ohio 43113

3. In particular, the GSDM:

   a. provides a globally unique location tag for each point.
   b. uses one set of equations world-wide. No zone constants are required.
   c. preserves geometrical integrity both locally and globally.
   d. is three-dimensional and does not distort distances as does a 2-D map projection. The grid/ground distance dilemma is solved.
   e. combines horizontal and vertical into a single 3-D data base.
   f. permits each user to know the 3-D positional accuracy of each point.

Model & Perspective

The best model is one that is at the same time simple and appropriate. Current horizontal and vertical models as used in geodesy and other spatial data applications are really not very simple but, given the traditional use of horizontal and vertical datums, have been used because they are more appropriate than the flat earth model. Burkholder (1998) describes various models used for spatial data, gives background and details of the GSDM, and includes equations for using the GSDM.

With advent of modern data collection instruments, electronic storage media, and geographic information systems (GIS's) the demand for spatial data has mushroomed. Productivity in map making skyrocketed because traditional manual processes were computerized and increases in productivity continue by using automated data collection and faster computers. But the question must be asked, "Are the underlying spatial data models really appropriate?" For the way humans visualize the world, the answer might be yes. But not for automated data collection, electronic processing, and digital storage. Modern GIS's have evolved from 2-dimensional data bases (state plane coordinates) to 2.5-dimensional systems where elevation is an attribute of location to pseudo 3-D systems in which state plane coordinates are used with elevations (called pseudo because elevations are referenced to an irregularly curved surface - the geoid). The next step is to use a truly 3-dimensional model that is both simple and appropriate--the GSDM which accommodates new technology, modern practice, AND permits each user to view the world from any perspective.

Perhaps that is the most novel idea associated with the GSDM. The origin of a local rectangular coordinate system travels with the user and is placed (or moved) at will. The unique three-dimensional location of each point is uniquely stored in the data base but, given a data set of points (10, 50, 1000 or millions), the user selects any point as the Point of Beginning (POB) and all other points are brought out of the data base with respect to the chosen POB. The technology of data visualization is already in place and it is possible to walk or fly through a proposed development using virtual reality. With the GSDM, the difference is that all points in the data base represent real world points. And, the added benefit is that the GSDM provides an efficient way to describe the spatial accuracy of each point--in three dimensions.

The GSDM is already defined and in place. It supports interoperability, it is seamless, simple, and rigorous, and data quality is defined in terms of standard deviations of each component. The term GSDM is generic and all equations used in the GSDM are public domain. The term BURKORD® is the name of prototype 3-D coordinate geometry software and is an adjective describing specific design of a 3-D data base.

Applications to Current Initiatives

Many persons and organizations are doing impressive things with digital spatial data. Decentralization and the freedom to innovate is fundamental to progress, but the importance of a simple standard underlying spatial data model is the point of this paper. The GSDM is a unifying concept which provides each researcher and user the luxury of complete freedom with respect to how spatial data are used. On the other hand, complete interoperability and compatibility are assured to the extent each user is also willing to define the relationship of their data base to the GSDM. In most cases, that is already being done by default if not by specific declaration.

The following list is incomplete, but intended to be somewhat representative of large-scale efforts which could benefit from adopting the GSDM as a matter of policy. It would not restrict the prerogative of any initiative, but it would insure compatibility between disciplines, between agencies, between government and industry, and between users all over the world.

Where appropriate, a web link is given and the reader is encouraged to visit each one for more information.

1. Digital Earth Initiative by NASA - http://digitalearth.gsfc.nasa.gov

2. National Integrated Lands System - www.blm.gov/nils

3. X-Y Project - www.fgdc.gov/standards/documents/proposals/ugrsprop.html

4. SRI's Digital Earth Project - www.ai.sri.com/digital-earth

5. International Global Grids Conference www.ncgia.ucsb.edu/globalgrids/ann.html

6. NAD 2000 project - www.ngs.noaa.gov/initiatives/NewRefSys/NSRSpolicy.html

7. The Web Mapping Testbed project sponsored by the Open GIS Consortium. See Photogrammetric Engineering & Remote Sensing (PE&RS), November, 1999, pp 1239 - 1241 and December, 1999, pp 1345 - 1359.

8. The National Academy of Public Administration efforts to establish a National Spatial Data Council, see PE&RS, November, 1999, pp 1231 - 1235.

References

Burkholder, E.F., 1999, "Spatial Data Accuracy as Defined by the GSDM," *Surveying & Land Information Systems*, Vol 59, No. 1, pp 26-30.

Burkholder, E.F., 1998, "A Practical Global Spatial Data Model for the 21st Century," presented at the National Technical Meeting of the Institute of Navigation, Long Beach, CA, January, 1998.

Burkholder, E.F., 1997, "Definition and Description of a Global Spatial Data Model," U.S. Copyright Office, Washington D.C.

Clinton, W.J. (President), 1994; "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure," Executive Order 12906, signed April 11, 1994, Federal Register, vol. 59, No. 71, pp 17671-17674. (see www.fgdc.gov/publications/documents/geninfo/execord.html)

DMA (Defense Mapping Agency), 1991, "Department of Defense World Geodetic System 1984: Its Definition and Relationships With Local Geodetic Systems," Technical Report 8350.2, Defense Mapping Agency (now National Imagery and Mapping Agency), Fairfax, Virginia.

Gore, Al, (Vice President), 1998, "The Digital Earth: Understanding our planet in the 21st century," (www.digitalearth.gov/speech.html) speech given at the California Science Center, Los Angles, California, January 31, 1998.

Leick, Alfred, 1995, "*GPS Satellite Surveying*," John Wiley & Sons, NY, NY.

Mikhail, Edward, 1976; "*Observations and Least Squares*," Harper & Row, New York, NY.

Wolf, P.R. and C.D. Ghilani, 1997, "*Adjustment Computations: Statistics and Least Squares in Surveying and GIS*," John Wiley & Sons, NY, NY.