The Gridded Map

Alden P. Colvocoresses

Abstract

One of the early evidences of civilization has been the map — a graphic depiction of a portion of the Earth's surface. Maps have evolved from crude drawings to highly refined maps and charts. There are three fundamental characteristics of good maps — content, currency, and accuracy. Content is largely a matter of scale, currency is the date of the map information, while accuracy determines how well one can locate positions and make measurements in a defined coordinate system. Today, the most suitable coordinate referencing system for large-scale maps is the Universal Transverse Mercator (UTM) grid. Most of the developed world now uses the UTM (or its equivalent) grid on its larger-scale maps, but the United States basic map series at 1:24,000 scale generally fails to do so. The evolution of hand-held Global Positioning System (GPS) units capable of delivering position accuracies to better than 10 m makes large-scale map gridding an item of immediate concern. Proper and complete gridding of this series should now be a top priority of the nation's mapping program.

Introduction

The known history of mapping the Earth dates back several thousand years (Brown, 1950; Wilford, 1981; Snyder, 1993). However, today only half the land areas of the Earth are mapped at scales which properly portray the works of man and nature. It is convenient to refer to such maps as "large scale," defined as representing a portion of the Earth's surface at 1:100,000 scale or larger. Because the Earth is a near sphere and a map is a two-dimensional portrayal, some distortion will occur on all maps. At large scale, only a relatively small portion of the Earth's surface is shown on a single sheet, and the resulting distortion is very small and may be ignored for most uses. However, if the large-scale mapping extends over a sizable area it must be compiled on a specific map projection (plane surface) on which the Earth's surface distortion can be defined and held to a usable level. Assuming the map has been accurately made, there must be some Earth referencing system for precise point location and distance measurement. Smaller-scale maps and charts normally carry latitude and longitude (lat/long) indicators which are ideal for sea and air navigation, and for precise geodetic control purposes.

Map projections treat the distortion resulting from representing the spherical Earth as a plane in a variety of ways but, over the years, most large-scale map users have found that the condition of conformality is the most compelling. Conformality means retention of true direction and local shape. Thus, mariners chose the conformal Mercator more than 400 years ago and have used it since that time.

During the 19th century the military, particularly in Europe, developed accurate artillery and demanded reliable, large-scale maps from which the accurate direction and range from gun to target could be determined. Like the mariners, the military chose the conformal projection concept.

There is a sizable family of different conformal projections and many were utilized for large-scale mapping into the early 1900s. World Wars I and II demonstrated the military need for a uniform system of conformal projections, and by the end of World War II, a consensus favored the Transverse Mercator for medium- and large-scale mapping. The Transverse Mercator involves lengthy north-south zones of the Earth bounded by prescribed meridians.

Development of Gridded Maps and Datums

A graticule of intersecting lines of latitude (parallels) and longitude (meridians) has long been the conventional way of describing positions on a map. However, the units of latitude and longitude are of different size (except near the equator) and this makes positioning and measurement both complex and time consuming. Because a large-scale map depicts a near-plane portion of the globe, the lat/long grid can be replaced by a Cartesian coordinate grid of truly straight lines and of equal spacing in both cardinal directions. This results in the so-called *x/y* grid commonly based on eastings and northings. Anyone with a modest education and a simple measuring device can precisely define a point in terms of *x/y*, and from two such points mathematically determine distance and direction. Assuming the map has been properly made, such an *x/y* gridded map becomes one of *scaling accuracy*. Even though the map has been folded or otherwise distorted, accurate positions can still be readily recovered by reference to the grid lines which should be no more than 10 cm (four inches) apart.

The advantages of gridded maps, particularly for field use, were first recognized by the military. Their conformal maps, starting in the early 1800s, were soon carrying the *x/y* grids. This was particularly true in Europe where the same regions were repeatedly contested. In North America, the military rarely had time to prepare much more than crude sketch maps and the *x/y* grid concept did not show up until well into the 20th Century. The United States military, shocked by their mapping deficiencies during World War II, took the lead in establishing a global system of medium- and large-scale gridded maps of the land areas of the world. The North Atlantic Treaty Organization (NATO) soon adopted the U.S. concept and by the mid-1950s a mapping system known as the Universal Transverse Mercator (UTM) had been accepted by the (western) military powers and was being implemented on a global basis. John O'Keefe (1952) describes this development. Basically, the UTM map projection and grid involve 60 Transverse Mercator zones of 6° width in longitude that extend from 80°S to 84°N latitude, with the polar regions based on polar stereographic projections. Figure 1 illustrates the UTM zones as they cover the 48 states. The UTM zones each have a maximum scale distortion of about 1:1,000. However, except in the equatorial region, this

3316 Rocky Mount Road, Fairfax, VA 22031.

Photogrammetric Engineering & Remote Sensing,
Vol. 63, No. 4, April 1997, pp. 377–380.

0099-1112/97/6304-377$3.00/0

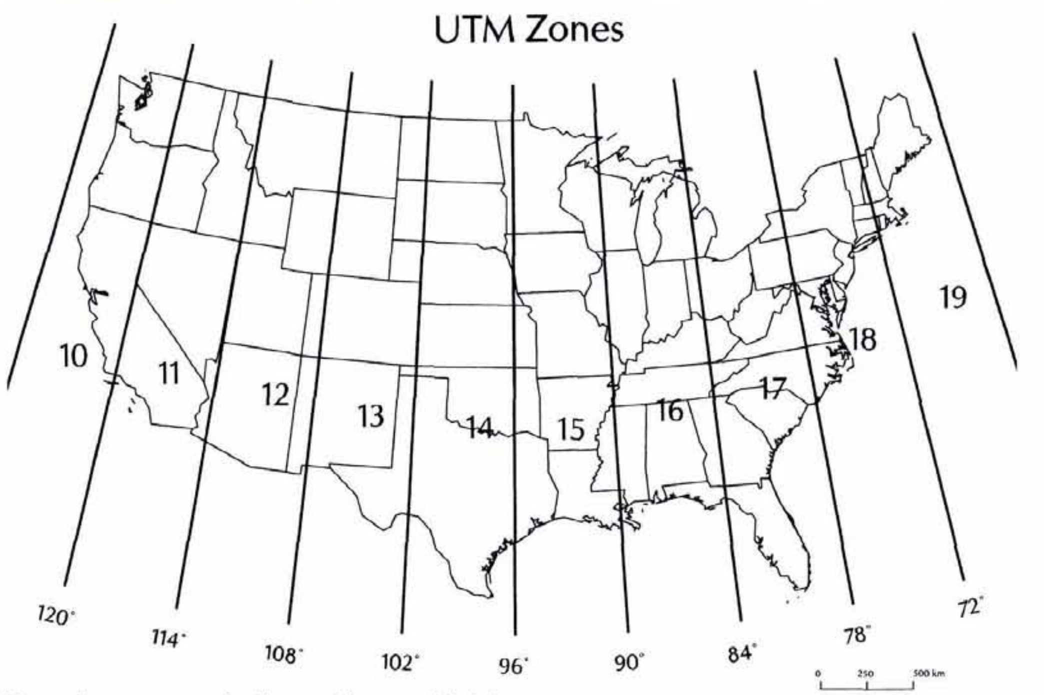

Figure 1. UTM zones for the contiguous 48 states.

distortion is limited to 1:2,500, a distortion (or error) too small to be measurable on a single large-scale map sheet. Furthermore, the distortion is mathematically defined so that it can be compensated for higher order surveying purposes. Understandably, the so-called Eastern Block (former Soviet Union and China) was not willing to follow a NATO scheme. However, their mapping is based on the same 6° Transverse Mercator zones as the UTM, but with the projections tangent rather than secant to the figure of the Earth. However, all this does is introduce a simple linear scale factor between the Soviet-Chinese system (generally known as the Gauss-Kruger) and the UTM (assuming the same ellipsoid is used).

The modern mapping of the United Kingdom (UK) deserves special mention with respect to the development of the gridded map (Harley, 1975). During the 1930s, a "blue ribbon" Davidson Committee called for the transformation of the myriad of existing maps of the UK to a single unified system. This system involved one Transverse Mercator projection (zone) for the whole country with a full *x/y* grid. Mathematically, the projection and grid are the same as the UTM, but the central meridian was moved from Greenwich (0°) to 2°W longitude so that one zone covered the country. World War II delayed implementation, but by 1970 the UK was well covered at scales as large as 1:1,250 (selected areas) and as small as 1:625,000, and all with the same projection and grid.

The use of the Transverse Mercator projection, and particularly the UTM, has expanded steadily since the early 1950s. Although the UTM is of military origin, it was soon adopted for civil use by numerous nations which did not already have a developed system of mapping in place. The United Nations, through its *World Cartography* publications, played a key role in gaining the acceptance of the TM projections (Colvocoresses, 1969; Brandenberger and Ghosh, 1983).

Today, nearly all large-scale topographic maps, civil as well as military, carry a full *x/y* grid. The one major exception is in the large-scale maps of the United States. During the late 1940s and '50s, the U.S. military completely mapped the United States at 1:250,000 scale with a full UTM grid. However, the civil edition of this series, and larger-scale series, all published by the U.S. Geological Survey (USGS), carried only UTM marginal ticks. In 1973, the USGS adopted the UTM as its preferred map projection and grid, and soon the 1:250,000- and 1:100,000-scale maps were carrying the full UTM grid. The UTM gridding of the nearly 54,000 large-scale maps of 1:24,000 scale was also initiated (Thompson, 1987). However, after 20 years of rather halfhearted effort, less than 30 percent were so treated. In fact, during 1994, the USGS actually began to remove the UTM grid from the 1:24,000 maps and replace the grids with marginal ticks (Figure 2).

Although global mapping was well on its way through the 1940s, '50s, and '60s, there was no agreement on the precise size, shape, and orientation of the mathematical figure of the Earth, and at least ten different Earth models, or ellipsoids, were being used throughout the world as the basis for mapping. It was not until the advent of the space age that humans had the capability of determining a "best" model for the Earth. This has resulted in two near-identical ellipsoid figures for the Earth: (1) the Geodetic Reference System of 1980 (GRS 80) and (2) the World Geodetic System of 1984 (WGS 84). The GRS 80 ellipsoid is the reference ellipsoid for the North American Datum of 1983 (NAD 83), and the WGS 84 ellipsoid is the reference ellipsoid for the WGS 84 datum.

With the development of NAD 83/WGS 84, it would appear that now all maps should be put on such a datum, but in fact this is not the case. Mapping is a slow, expensive operation and converting maps from one datum to another is no simple task. Thus, most of today's maps are generally cast on what many consider to be obsolescent datums. Nearly all current maps of North America, for example, are based on the North American Datum of 1927 (NAD 27). Cartesian (*x/y*) grids are tied to specific datums and as datums change so must the grids.

Current Status of Grids on USGS Large-Scale Maps

As of late 1996, the status of gridding the 1:24,000-scale series is anything but clear. A USGS draft instruction dated 8 December 1995 calls for the reinstatement of the full UTM grid, but this instruction remains to be approved. Moreover,

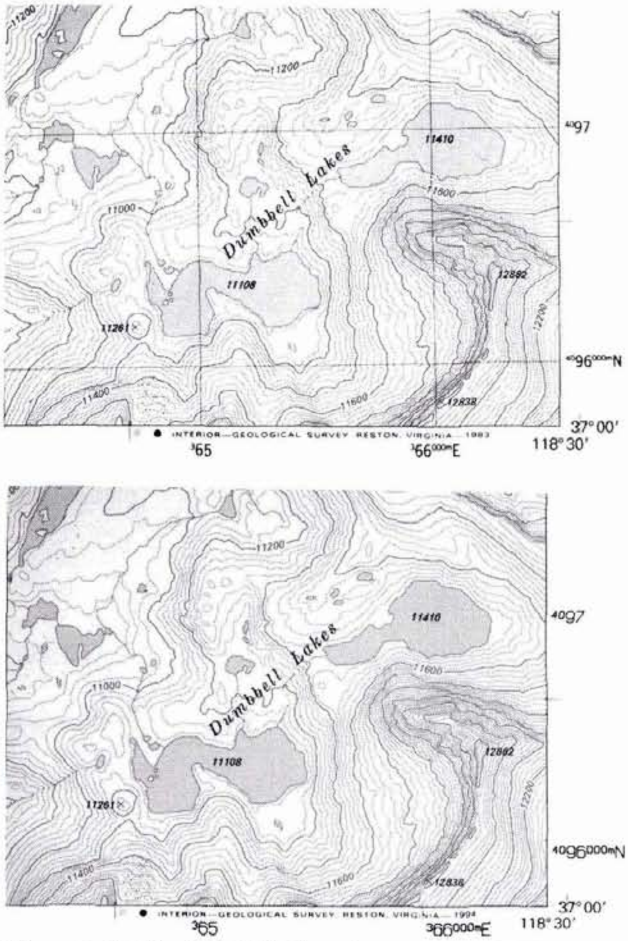

Figure 2. Gridded (1982/83) and non-gridded (1994) sections of the USGS North Palisades, California, 1:24,000-scale topographic quadrangle. Note: the UTM grid has been removed from the more recent (1994) version of this map (bottom).

this instruction eliminates the 11,000 to 12,000 sheets covered by a joint USGS/U.S. Forest Service (USFS) agreement. If this instruction is implemented, about 20 percent of the conterminous United States would be covered with ungridded 1:24,000-scale maps. The ungridded areas are widely scattered, resulting in a crazy-quilt pattern between the gridded and ungridded sheets.

Why Grid Our Maps?

The United States is about the only developed nation that does not carry a full *x/y* grid on its standard large-scale map series. Reasons for having the UTM grid on USGS map products may be summarized as follows:

- *Expressed Need for the UTM Grid.* The U.S. military has clearly expressed a requirement for fully gridded 1:24,000-scale maps (1:63,360 for Alaska) in order to perform the wide range of activities that involve military deployment. The National Association for Search and Rescue has likewise requested the UTM grid on large-scale maps. Until the 1970s the UTM was virtually unknown in the United States, except by the military. However, during the past few years, more and more civil needs requiring the use of UTM coordinates have developed. Today, only one federal agency, the USFS, is opposing the UTM gridding of our large-scale maps.
- *Global Positioning System (GPS).* Today the GPS is revolutionizing the surveying and mapping field. The current accuracy of single, hand-held GPS units in civilian use for ground point location (with Selective Availability turned on) is on the order of 50 to 100 m. However, the military and most government agencies have access to hand-held GPS units that utilize the "P" or "Y" codes that give position accuracies to approximately 10 to 20 m, and civilians can make use of small commercial receivers capable of real-time differential corrections to determine positions to well within 10 m. As the positional accuracy of the 1:24,000-scale maps is about 10 m, to fully utilize the accuracy of the GPS one must be able to readily locate the position on a map. To do this, the map must carry a grid and the most suitable grid for such a purpose is the UTM.
- *Uniformity.* The large-scale maps of both Canada and Mexico carry the full UTM grid. For uniformity, we should have the full UTM grid on the U.S. large-scale maps as is currently done on our maps of smaller scale. International planning and GIS studies would be greatly facilitated. A single system of mapping would also ease the educational problems associated with map use.
- *Accuracy.* The grid permits the map user to retain the original accuracy of the map for positioning and measurement purposes. This is particularly true for maps that have been folded and/or subjected to humidity changes.

There are three common objections to the UTM grid: (1) it is of military origin, (2) it is metric, and (3) the UTM grid lines and those of the Public Land Survey System (PLSS) may create clutter and confusion. The first two objections are considered to be relatively inconsequential, but the third is a serious matter and is the reason the USFS objects to the UTM grid. The PLSS exists in most western and midwestern states, and its land lines and numeric designations are critical features that must be shown on the 1:24,000-scale maps. However, the PLSS lines are not a uniform grid and contain numerous irregularities. They simply are not suitable to be used as a precise referencing system to the figure of the Earth.

Confusion between UTM and PLSS land lines has been a subject of considerable study. However, it was decided 30 years ago that UTM lines should be black and PLSS lines red and of different thickness. Of course, when the standard multicolor map is copied into single color form, this distinction is largely lost. However, the cost of the standard multicolored map is reasonable ($4.00) and copying them into single color form is a questionable economy. Minimizing the confusion between the two sets of lines is a challenge to the cartographer, but hardly one that cannot be properly met, as it has by others.

Summary and Forecast

The Earth is now recognized as a single mathematically defined figure (or model). This model should be utilized for all precise mapping, including the definition of the required projection planes. Of the projections available, the Transverse Mercator is considered the most practical for extensive medium- and large-scale land mapping. In North America, the UTM has been acknowledged as the projection of choice for country-wide mapping. A person using a hand-held GPS receiver may soon be able to locate positions to within 10 m in a common global system. The current 1:24,000-scale maps of the United States provide similar accuracy, but do so with respect to a more or less outdated datum (NAD 27). An obvious solution to this problem is to recompile the nearly 54,000 sheets onto the NAD 83 datum, but such drastic action is not required. A much simpler solution is to leave the compilation intact, revalue the original sheet corners according to NAD 83, and revise the marginal text as required. A NAD 83 UTM grid must be added to the black compilation plate. Using this concept, the U.S. Defense Mapping Agency,[1] in co-

[1]Integrated into the National Imagery and Mapping Agency (NIMA) on 1 October 1996.

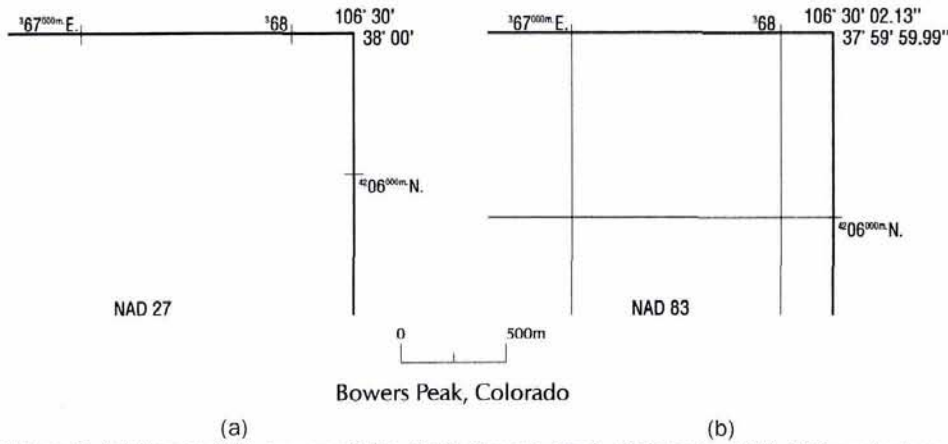

Figure 3. (a) Upper right corner of the USGS Bowers Peak, Colorado, 1:24,000-scale topographic quadrangle as currently cast on NAD 27. (b) The geographic coordinates of the map corner have been re-labeled for NAD 83 and a NAD 83 UTM grid superimposed to demonstrate the possibility of providing updated coordinate reference systems without changing the content of the map.

operation with foreign governments, has already produced large-scale map series of sizable areas based on the WGS 84 datum. This procedure promises a ten-fold saving in time and literally millions of dollars as compared to recompiling the 1:24,000-series from NAD 27 to NAD 83. This procedure is illustrated by Figure 3 which depicts a corner of the 1:24,000-scale Bowers Peak, Colorado quadrangle revalued to NAD 83 lat/long coordinates and with the NAD 83 UTM grid superimposed. Note that the basic map compilation remains intact.

There is now considerable discussion suggesting that NAD 83 is not an adequate datum and that consideration should be given to newer ones such as the International Terrestrial Reference Frame (ITRF) which would change NAD 83 values on the reference ellipsoid by one or two metres, but also would involve a continuing change of surface point values by as much as one metre every ten years. Such a change would defeat the whole concept of a datum for mapping and surveying which must remain fixed for a reasonably long period of time such as 100 years.

The UTM gridding of our large-scale maps on either the NAD 27 or NAD 83 should be an item of highest priority in the nation's mapping program for the 21st Century. Of course, this leaves the decision between NAD 27 and NAD 83 as an item that must be resolved without further delay. If the national decision is to convert to NAD 83, then funds must be made available to accomplish this conversion within a reasonable time period, say five years. If such funds are not made available, then the NAD 27 datum should be retained and strengthened with the UTM (NAD 27) grid being added to all of the standard large-scale maps of the United States.

References

Brandenberger, A.J., and S.K. Ghosh, 1983. World Cartographic Mapping, 1980, *World Cartography*, Volume XVII, United Nations, New York, pp. 4–38.

Brown, L.A., 1950. *The Story of Maps*, Little, Brown and Company, Boston, 397 p.

Colvocoresses, A.P., 1969. A Unified Plane Reference System, *World Cartography*, Volume IX, United Nations, New York, pp. 9–65.

Harley, J.B., 1975. *Ordnance Survey Maps*, Her Majesty's Stationery Office, United Kingdom, 200 p.

O'Keefe, J.A., 1952. The Universal Transverse Mercator Grid and Projection, *The Professional Cartographer*, Journal of the Association of American Geographers, Volume 4, Denoyer-Geppert Company, Chicago, Illinois, pp. 19–24.

Snyder, J.P., 1993. *Flattening the Earth*, The University of Chicago Press, Chicago, Illinois, 365 p.

Thompson, M.M., 1987. *Maps for America*, Third Edition, U.S. Government Printing Office, Washington, D.C., 265 p.

Wilford, J.N., 1981. *The Mapmakers*, Alfred A. Knopf, New York, 414 p.