Map Conversion and the UTM Grid

Frederick J. Doyle

Abstract

Papers in this issue of Photogrammetric Engineering & Remote Sensing *by Welch and Homsey, Colvocoresses, and Terry address the conversion of coordinates from the North American Datum of 1927 (NAD 27) to the North American Datum of 1983 (NAD 83), and address the representation and utility of the Universal Transverse Mercator (UTM) coordinate grid on U.S. Geological Survey (USGS) 7.5-minute, 1:24,000-scale quadrangles. Problems related to datum and coordinate conversion, UTM map grids, International Terrestrial Reference Frame (ITRF), and terrain elevations derived from Global Positioning System (GPS) survey techniques are reviewed in this paper, and the geometric foundation for coordinate systems and map products are presented. Professional mapping societies must provide education on these problems as related to the need to extend the utility of the large scale maps of the United States into the 21st century. Mapping agencies such as the USGS will be required to take steps necessary to insure the currency of the 1:24,000-scale map series.*

Introduction

The following three papers in this issue of *Photogrammetric Engineering & Remote Sensing* — "Datum Shifts for UTM Coordinates" by R. Welch and A. Homsey, "The Gridded Map" by A. Colvocoresses, and "Field Validation of the UTM Gridded Map" by Major N.G. Terry, Jr., USMC — address a situation that increasingly affects the continued utility of the U.S. Geological Survey (USGS) 7.5-minute, 1:24,000-scale quadrangles and the geometric reliability of information derived from these maps. There are three separate, but related, problem areas: (1) conversion of map and survey data from the North American Datum of 1927 (NAD 27) to the North American Datum of 1983 (NAD 83), (2) adoption and representation on maps of the Universal Transverse Mercator (UTM) coordinate system, and (3) determination of terrain elevations from Global Positioning System (GPS) observations as related to vertical datums. An overview of these problem areas is provided, along with a geometric foundation that will facilitate an understanding of mapping problems and user requirements as we enter the 21st century.

Geodetic Datum Conversion

The traditional definition of a geodetic datum requires a surface, a point of origin, and a reference direction to provide a basis for establishing horizontal positions. Typically, the surface is an ellipsoid of revolution whose polar axis is parallel to the axis of rotation of the solid Earth; the point of origin is the latitude, longitude, and geoid height (approximately — the elevation of Mean Sea Level with respect to the ellipsoid) assigned to a given survey point; and the direction is the geodetic azimuth to an adjacent survey point. A geodetic datum is established by making a best fit to a network of adjusted triangulation survey points over an extended area.

The NAD 27 was derived from the geodetic survey network available at that date (National Academy of Sciences, 1971). Its reference surface is the 1866 Clarke ellipsoid, the point of origin is triangulation station Meades Ranch in Kansas, and the azimuth is given to triangulation station Waldo. The national map series in the United States was based on this datum, which was also adopted by Mexico and Canada.

Over the last 70 years, much additional precise survey data have been accumulated. Transcontinental traverses were completed, Doppler satellite positioning was accomplished, extensive astro-geodetic deflections were observed, and world-wide gravity observations became available. Most significantly, artificial Earth-orbiting satellites and intercontinental missiles were developed with the orbits of these vehicles controlled by the center of mass of the physical Earth. All of these factors combined to make it both feasible and expedient to compute a new geodetic datum which would be world-wide in application and whose origin would be at the center of mass of the physical Earth. Both the Department of Defense and the National Geodetic Survey cooperated in determining parameters for the new system. Table 1 in the paper by Welch and Homsey shows the differences between the NAD 27 and NAD 83 ellipsoids. The semi-major axis a (equatorial radius) for each ellipsoid is given. The semi-minor axis (polar) b can be determined from the flattening $f = (a-b)/a$, which is given in the table. If this computation is carried out, the following values are obtained:

Datum	Equatorial a	Polar b
NAD 27	6378206 m	6356584 m
NAD 83	6378137 m	6356753 m

Thus, the NAD 83 ellipsoid is shorter in the equatorial dimension and longer in the polar dimension than the NAD 27 ellipsoid. For some reason, the Department of Defense adopted a slightly different flattening for the World Geodetic System of 1984 (WGS 84). But this results in less than one metre difference in the polar dimension as compared to NAD 83. The orbits for the NAVSTAR GPS spacecraft are computed in WGS 84, but there is no significant difference in ground station positions determined in NAD 83 or WGS 84.

Figure 1a shows diagramatically how changes in the dimensions and origin of the ellipsoid affect both geodetic latitude and the Northing grid coordinates of points on the Earth's surface. Similar changes are affected in geodetic longitude and Easting grid coordinates. As mentioned in the paper by Welch and Homsey, the shifts (or differences) in geodetic coordinates (lat/long) in metres between NAD 27 and NAD 83 graticule position locations have been documented in *USGS Bulletin 1875* for the corners of all 7.5-minute map sheets. But there has been considerable confusion about the NAD 27 to NAD 83 shifts in UTM coordinates. *The shifts in*

Photogrammetric Engineering & Remote Sensing,
Vol. 63, No. 4, April 1997, pp. 367–370.

0099-1112/97/6204-370$3.00/0

1591 Forest Villa Lane, McLean, VA 22101.

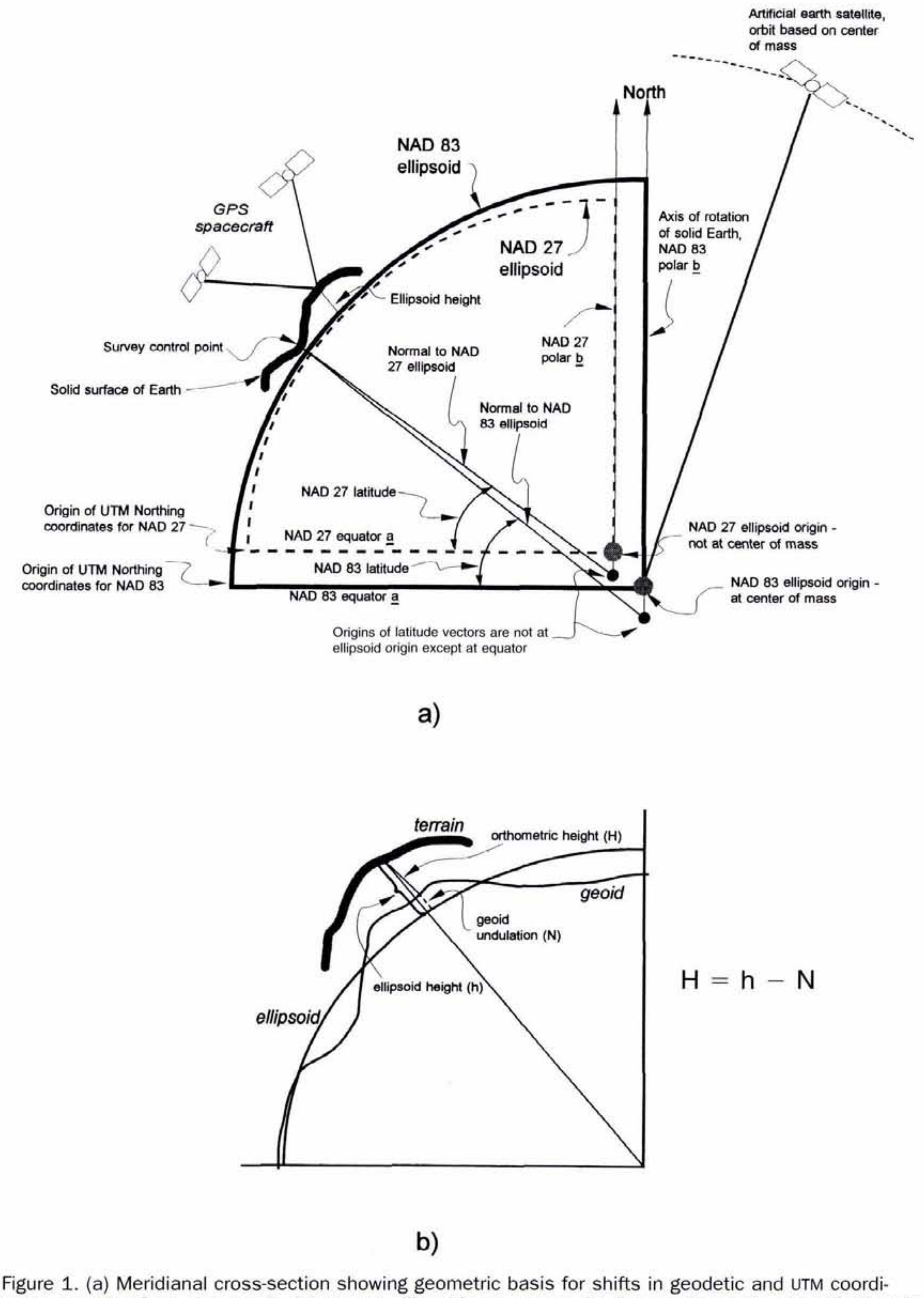

Figure 1. (a) Meridianal cross-section showing geometric basis for shifts in geodetic and UTM coordinates resulting from changes in datum and ellipsoid parameters. (b) Schematic relationship of ellipsoid and geoid to terrain surface.

UTM coordinates are not the same as the metre values for the graticule, because the length of a degree of latitude or longitude depends upon the dimensions of the ellipsoid, but the length of the metre remains fixed. Added to this is the effect of the change in the point of origin of the UTM coordinates.

Welch and Homsey document computer programs which are available for determining the UTM coordinate shifts between NAD 27 and NAD 83, and recommend procedures for making the shift values more readily available to the map user. One can only support these recommendations.

The UTM Grid on Map Series

In the following papers, Colvocoresses makes the case for including the full-line UTM grid on all national map series. Terry documents (1) the superiority of the full-line UTM grid (to marginal ticks) for quickly and accurately determining locations, and (2) a map user preference for rectangular UTM grid coordinates (rather than lat/long values) for field navigation tasks. In view of these facts, it is fair to ask why the full-line grid is not now shown on all standard map series. Colvocoresses notes the U.S. Forest Service (USFS) objections to the UTM grid because it can be confused with Public Land Survey lines on monocolor copies of standard maps. This seemingly frivolous objection has serious consequences because the USGS National Mapping Division depends upon the USFS to maintain all 7.5-minute 1:24,000-scale quadrangles that contain USFS lands. Furthermore, the USFS has decided not to convert their maps and data to NAD 83. Colvocoresses describes the vacillation of the USGS in adding the full-line UTM grid to the standard maps, but apparently the current policy is now to include the grid except in the 20% of the quadrangles which include USFS lands. The map user community can only applaud this decision and hope it does not change again. Perhaps the USGS and USFS will also agree that the full-line UTM grid should be included on all 1:24,000-scale maps.

Map Datum Conversion

While putting grids on maps is a relatively easy thing to do, converting from the old NAD 27 to the new NAD 83 is not so easy. Most of the existing maps were cast on projections based on NAD 27. To provide NAD 83 information, the USGS had been adding supplemental tick marks at the corners of each map sheet showing the displacement of the graticule, and marginal notes giving the displacement in metres to convert NAD 27 sheet corner values to NAD 83. Unfortunately, many users assumed that the same changes should be applied to the UTM grid coordinates, and this of course is not true. Marginal notes do not explain the difference between "projection lines" (i.e., graticule) and the UTM grid (Featherstone and Langley, 1997).

To recompile the maps on NAD 83 requires that a strip of detail up to several millimetres wide be eliminated from one edge of the map sheet while a strip of comparable dimension be added to the opposite edge. This is an enormous and expensive task for the 54,000 quadrangles in the 1:24,000-scale map series. Colvocoresses describes an interim scheme to designate the existing 7.5-minute sheet corners with their actual values in NAD 83. The UTM grid would be shown in its correct location for the NAD 83. This scheme has already been applied by Defense Mapping Agency (DMA) for a number of maps in foreign areas. A marginal note must also clearly indicate whether the 2.5-minute graticule intersections within the interior of the map quadrangles have been moved to their new locations on NAD 83, or retained in their original NAD 27 positions.

There is a trend in both military and civil mapping agencies to eliminate stockpiles of printed paper maps in favor of "print on demand" from digital files of map feature data. In principle, it should be relatively easy to assemble and edit these digital files in order to make the datum conversion from NAD 27 to NAD 83. Although cost issues remain to be resolved, the USGS, to its credit, has undertaken to reformat the 1:24,000-scale series using this procedure. However, at the moment, the line quality of the output graphic products is not satisfactory. It is hoped that the USGS will continue its research efforts to improve quality, and will then make a strong commitment to complete the datum conversion in a short period of time. For the moment, it appears that map users will be confronted with at least five types of 1:24,000-scale quadrangle map products:

- Ungridded maps on NAD 27 in areas containing USFS lands,
- Ungridded maps on NAD 27 for many non-USFS areas,
- Ungridded maps on NAD 83 in USFS areas,
- Gridded maps on NAD 27, and
- Gridded maps reformatted on NAD 83.

There is an obvious need for strong policy guidance and budgetary support — possibly including Congressional direction — before the nation's primary map series will be unified on a single modern datum, and carry the preferred UTM plane coordinate reference system.

International Terrestrial Reference Frame

Much to the chagrin of cartographers, the Earth's surface is not absolutely static. Continued tracking of Earth-orbiting spacecraft (primarily those in the GPS constellation) indicates that the current center of mass of the Earth is displaced from that used in WGS 84 and NAD 83 by as much as 2 metres. Furthermore, tectonic plate motions and other esoteric astronomic factors impart small translational and rotational velocities to sets of station coordinates (SSCs). Modern high precision measurement techniques are able to detect these motions which are generally less than 10 cm per year. The International Terrestrial Reference Frame (ITRF) is established and maintained by the International Earth Rotation Service Central Bureau in Paris, France, and its parameters are published annually (Boucher and Altamimi, 1996). A spokesperson at NGS states that there is no intention of imposing ITRF as a continually changing datum for maps and surveys. The real effect is on the ephemerides of the GPS satellites, and the published values for GPS users will take the annual motions into account so that positions determined by GPS will relate to WGS 84.

Terrain Elevations from GPS

Though not discussed in the papers by Welch and Homsey, Colvocoresses, and Terry, the problem of determining terrain elevations from GPS observations is so closely related that it seems worthy of brief comment. The ability of GPS to establish accurate horizontal control is widely accepted, and differential elevation accuracy over limited areas is nearly as good. Absolute elevation accuracy is limited by knowledge of the *geoid* — which is a surface closely approximating Mean Sea Level. Its shape is affected by topography and mass anomalies in the Earth's crust. At any point, the elevation determined directly from the GPS geometry is the elevation (h) of the terrain above the reference ellipsoid. As shown in Figure 1b, to convert this to the conventional orthometric height (H) above Mean Sea Level, the height of the geoid (N) referenced to the ellipsoid must be subtracted from the ellipsoid height. That is, $H = h - N$. World-wide geoid heights (for WGS 84) range from plus 75 to minus 104 metres. In the conterminous U.S. the geoid is always below the ellipsoid, with values ranging from -5 to -53 m.

The NGS has developed an improved model, GEOID 96, with a lat/long grid spacing of 2 minutes (Cheves, 1997). At each post the value is given to convert GPS ellipsoid heights to the latest North American Vertical Datum of 1988 (NAVD 88), with an accuracy of ± 6 centimetres. Appropriate use of GEOID 96 takes surveyors closer to the goal of using GPS for every day three-dimensional surveying.

Conclusion

The combination of NAD 83, UTM coordinate grids, the most current geoid model (GEOID 96), and GPS satellites represents major steps forward in the accuracy, completeness, interchangeability, and utility of map information. The professional societies need to take an active role in encouraging government agencies to move rapidly in implementing these systems, and in educating map data users — government, commercial, academic, and the general public — with the utility and advantages which will result.

References

Boucher, Claude, and Zuheir Altamimi, 1996. International Terrestrial Reference Frame, *GPS World*, 7(9):71–74.

Cheves, Marc, 1997. NGS releases new geoid model, *Professional Surveyor*, 17(1):49–51.

Featherstone, Will, and Richard Langley, 1997. Coordinate and datums and maps! Oh My!, *GPS World*, 8(1):34–41.

National Academy of Sciences, 1971. *North American Datum*, National Ocean Survey contract report E-53–69(N), 80 p.