THE BASICS OF CLASSICAL DATUMS

This is a revision of the first column on Grids and Datums that appeared in the July 1997 issue of *PE&RS*. The U. S. Global Positioning System (GPS) satellites have revolutionized surveying and mapping activities. First-order astronomical theodolites are now displayed in museums. Classical triangulation is no longer performed outside of academic instruction because of the enormous cost-savings afforded by differential GPS techniques. However, the fruits of centuries of detailed, *and largely reliable*, classical surveys are the foundation of today's national topographic maps existing in every country throughout the world. When we venture into a "new" mapping project, there is some pre-existing survey and map data that will have to be incorporated into that data set. Although a GPS-controlled project is largely free of systematic error when properly executed, the prospect of quantifying the systematic error of an older data set and incorporating that older data into the new system can be daunting. A successful mapping project depends on the merging of the old with the new. An understanding and knowledge of past practices, techniques, and reference systems is the pre-requisite to that success.

The primary coordinate reference system is the DATUM. The classical horizontal datum always starts at some particular point. Most datums have their historical origins at an astronomical observatory, mainly because when geodetic reference systems originated, the best-known position in a country was at that national observatory. That observatory also had a "mire" or reference point on the horizon with a known azimuth from true north (North Celestial Pole). With a known direction reference and a known position, physically measuring a distance to another point on the ground allowed the computation of another known position (Latitude and Longitude) with reference to the datum origin point. That's how all datums started. The observatory for the "mature" North American Datum of 1927 (NAD 27) was not in Kansas but on the East Coast. That is because "mature" datums are a result of more than one computation or adjustment. NAD 27 is based on earlier datums that included the New England Datum of 1879, the United States Standard Datum of 1901, and the North American Datum of 1913.

Many of these origin points were also Prime Meridians (zero Longitude) because observatories established an *ephemeris* of their own for predicting positions of heavenly bodies with respect to their own reference meridian. For instance, classical horizontal datum origins that had their own Prime Meridians include: Amersfoort, Netherlands; Bogota, Colombia; Dehra Dun, India; Tokyo, Japan; Madrid, Spain; Athens, Greece; Quito, Ecuador; Ferro, Canary Islands; Singkawang, Borneo; Potsdam, Germany; and, Greenwich, England.

When we map an area, we first establish control points that encompass the entire area. We interpolate — not extrapolate — when we map, and we use a coordinate reference system of some sort. The establishment of a datum from a starting point required many points to be determined in order to provide control for a national or regional mapping program. The electronic distance meter that used light waves was invented in the late 1940s in Sweden. The less expensive implementation with microwaves was later developed in South Africa. Prior to that, tapes were used in the 20th century that were made of a quench-annealed nickel-steel alloy called invar. Geodetic surveyors of the late 18th and 19th centuries did not have that technology available, so they had to use other types of length-measuring devices. Measuring distances was extremely difficult and time-consuming. Triangulation baselines sometimes involved entire seasons for dozens of surveyors and helpers in the determination of a single 20-30 kilometer distance. The Royal Court of England actually followed the survey of a baseline by having a series of picnics to watch the length measurement! Of course, after a baseline was determined to be reliable by separate, independent measurements, the last thing those geodetic surveyors wanted to do was to measure another baseline anytime soon. Triangulation techniques were developed to minimize the need for physically measuring distances on the ground. The basic mathematical formula they used for this purpose was the Law of Sines:

$$\frac{a}{\text{Sin A}} = \frac{b}{\text{Sin B}} = \frac{c}{\text{Sin C}}$$

Of course, there are many corrections needed for systematic error, but the basic principle of classical triangulation is just this simple. These points were observed as part of basic figures called quadrilaterals (four-sided), with all points being visible and all angles observed from all other points in the quadrilateral. Within each quadrilateral there is an over-determination of lengths which is used in a least-squares solution. Tens of thousands of quadri-

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laterals observed throughout the world were run predominantly in North-South directions to obtain a best-fitting figure of the Earth for the region under observation. Because of many starting points (datum origins), with hundreds of crews and thousands of different instruments and length-measuring devices, we wound up with many different determinations of the size and shape of the Earth (ellipsoids). Over time, many of the various ellipsoids never got past a single publication, while several dozen bcameommonly used for actual mapping in different parts of the world. Ellipsoids were named after the geodesist that computed and published the values along with the year of the publication, such as the Clarke 1866, the Bessel 1841, and the Walbeck 1819 — all once used in the United States!

Since datums evolve with time, some ellipsoids have evolved as a result of the re-adjustment of a datum such as in Great Britain. In some cases, ellipsoid parameters were modified as a result of the adoption of new length standards such as new "meter bars" in South Africa and the Palestine. Classifying data types and coordinate systems in terms of specific map projections and ellipsoids is a common mistake; the most important classifier is the datum and its adjustment date. Therefore, once the specific datum is identified, all other parameters follow by definition. For instance, the North American Datum of 1927 origin is at Meades Ranch, Kansas where: $\phi_o = 39° 13' 26.686''$ North, $\lambda_o = -98° 32' 30.506''$ West of Greenwich, and geoid height = zero. The defining geodetic azimuth to station Waldo is: $\alpha_o = 75° 28' 09.64''$, and the ellipsoid of reference is the Clarke 1866 where the semi-major axis a = 6,378,206.4 m, and 1/f = 294.9786982. The geoid height and direction of the gravimetric plumb line completed the definition. Datums vary in accuracy and reliability according to how various points were surveyed. The classical triangulations have evolved in accuracy because of improvements in instrumentation, field procedures, and adjustment techniques. Furthermore, intersection points were observed for topographic mapping by plane table and alidade as well as with photogrammetric methods, but at a drastically lower level of accuracy than the basic quadrilaterals. Many intersection points could not be realistically occupied such as church spires, roof finials, and water tanks.

Although a datum defines the basic control for a region or continental area, the accuracy of a datum varies according to the "order" of the original survey. Relating two datums to each other is valid only when we can identify common points that are part of main triangulation arcs. The chains of quadrilaterals represent the actual observations made over decades of datum development. Transformations are valid only when we relate chains of like accuracy, or "order," for a given region. The larger the region for which we attempt to develop a relation, the larger the uncertainty we obtain for our relation. We sometimes use additional parameters to define a relation so that we can decrease the uncertainties for a region or given data set. When we establish control for a mapping project with GPS receivers, eventually we will have to relate old data to our new maps. If we undertake this task in the United States, it's a pretty straightforward and well-documented procedure thanks to the National Geodetic Survey. The free Public Domain Datum-shift software packages "NADCON" and "GEOID99" are current solutions for the U.S. However, the datums that exist for the rest of the world are myriad; there are over 1,100 classical horizontal geodetic datums existing in the world. Datum-shift software is published by other nations, but excepting Australia; the packages are not free in Canada, Norway, South Africa, Switzerland, etc. The cartesian (X, Y) coordinate systems used for large-scale topographic maps (>1:50,000 scale) number over 3,200 known legal Grid Systems. For instance, the common U.S. military grid system, known as "UTM," that is used with numerous ellipsoids and 60 zones in two hemispheres, represents *only one system* out of that enormous 3,200+ inventory number!