Horizontal Datums
Knowing where in the world you are

Maralyn L. Vorhauer
Geodesist
National Geodetic Survey

A major concern of people everywhere is to know where they are at any time and how to get where they are going. The determination of such positions on the earth's surface and their relationship is a primary concern of the science of geodesy and the scientists called geodesists. Understanding and using datums form an integral part of this positioning.

Geodesy is defined as the science of determining the size and shape of the earth. Geodesists are concerned with the precise measurement of various physical properties of the earth in order to determine these values as accurately as possible. As these measurements become more and more precise, the earth's size and shape can be more and more accurately represented. This knowledge of the size and shape of the earth enables more precise positioning of points on the earth's surface-such as a boundary, a road or even a car. To compute these positions, this knowledge of the size and shape of the earth must be known. However, the earth is not a regular surface, so a figure must be used which represents as closely as possible the irregular shape of the earth so as to allow computation of positions on the surface using known mathematical equations. This figure has been found to be an ellipsoid.

Still, determining an accurate model for the earth is only the first step in computing an accurate position of a point on the surface of the earth. The difference at any point between the model of the earth and the physical location of the point on the earth must also be computed (this difference is called the geoid model). Many measurements are involved in the determination of the geoid model: e.g. the gravity field of the earth, astronomical observations (for spatial and temporal orientation), and studies of earth movement (how is the position of a point affected by plate tectonics as well as other physical forces). These measurements are used to form models which can be applied to any point rather than having to make such observations at all points for which one might wish to know a position.

The next step is to relate all points in such a way that they form a unified system. One can then determine distances and directions between such points reliably and accurately. This system is known as a horizontal datum. Historically, horizontal datums have been defined by the ellipsoid parameters being used for the mathematical equations and the latitude and longitude of a single point on that ellipsoid with an azimuth to another close-by point for orientation. This latitude, longitude and orientation are determined by astronomical observations. At this 'datum point', the ellipsoid and the surface of the earth are considered to be the same. This method of defining a horizontal datum has served well for even continental sized networks of points for hundreds of years. Today, however, it does not support the accuracy needed for relating points globally or for points computed from observations using new technology such as GPS (the Global Positioning System). Therefore, modern horizontal datums are more likely to be defined by positions determined from satellites and an ellipsoid centered at the mass center of the earth (since the satellites circle the earth). The concept of a datum or a unified system of points is also applied to other quantities such as the system defining the elevations above sea level of points on the earth's surface. Other datums are discussed in additional detail in other papers, see: http://celebrating200years.noaa.gov/magazine/vertical_datums/welcome.html.

Since its inception 200 years ago, NOAA's National Geodetic Survey-then known simply as Survey of the Coast-has had as its mandate the accurate determination of points on the earth's surface. The earliest observations were made to provide control for shipping along the coastlines of the US-starting with the Atlantic, and then expanding to include the Pacific and Gulf coasts as the nation grew.

Initially, computations of the surveys undertaken by the Coast Survey used the Bessel ellipsoid, named after Fredrich Wilhelm Bessel, a famous mathematician and astronomer of the early 19th century. Many countries today still use this ellipsoid for their defining figure of the earth.

The first official datum of the United States was the New England Datum. Adopted in 1879, it used the Clark Ellipsoid of 1866 and a mark in Maryland known as PRINCIPIO as its datum point. This ellipsoid was chosen because it best fit the shape of the United States and this minimized the problem of accounting for the differences between the ellipsoid and the actual position on the ground. The Pacific Coast was added when the first geodetic survey spanning the entire country was completed in 1899. Also, during these intervening years, the Gulf Coast was connected to the network.

With many observations and positions added in a piecemeal fashion, and with the datum point centered on the east coast, it became necessary to redefine the datum in 1901 to maintain the accuracy of the points, see Figure 1. For this re-computation, the ellipsoid was retained but the datum point was moved to a marker called MEADES RANCH (see Figures 2, 3, & 4), in Kansas and the datum was renamed the United States Standard Datum. After the geodetic organizations of Canada and Mexico formally agreed to base their networks on the US network, the datum name was changed to the North American Datum.

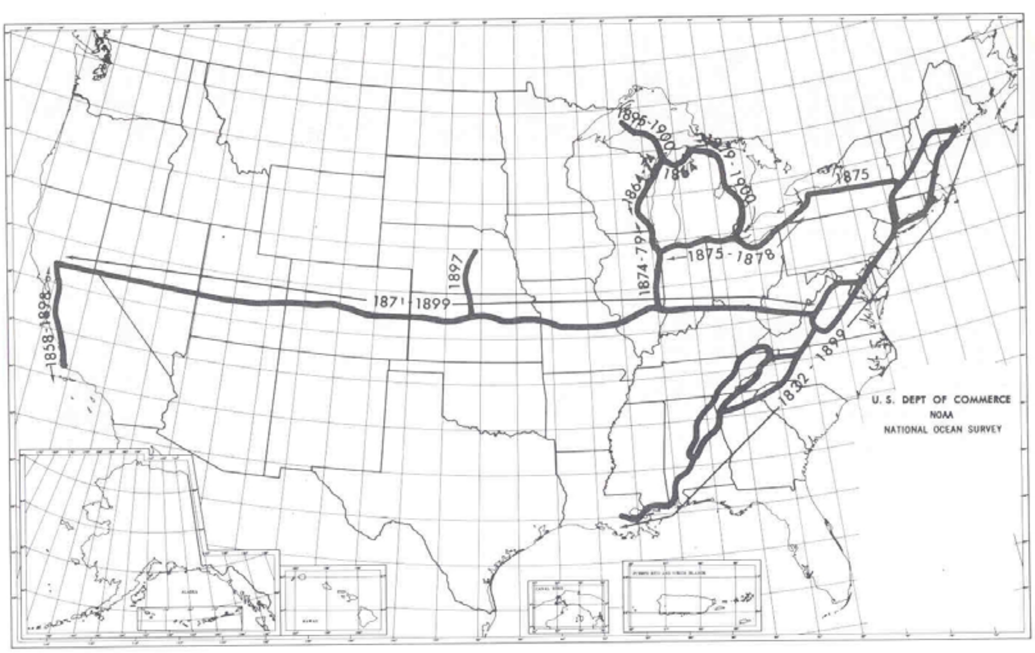


Figure 1
Geodetic Control For 1901 Adjustment - The North American Datum

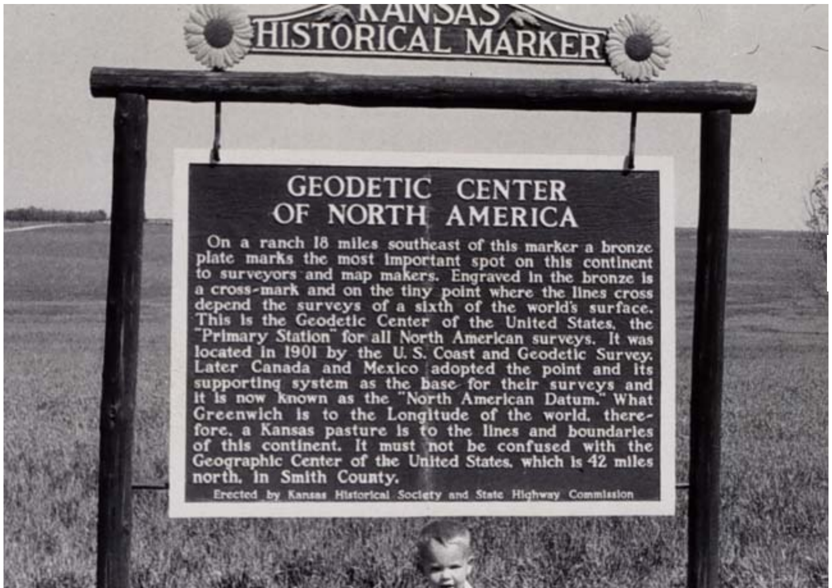


Figure 2

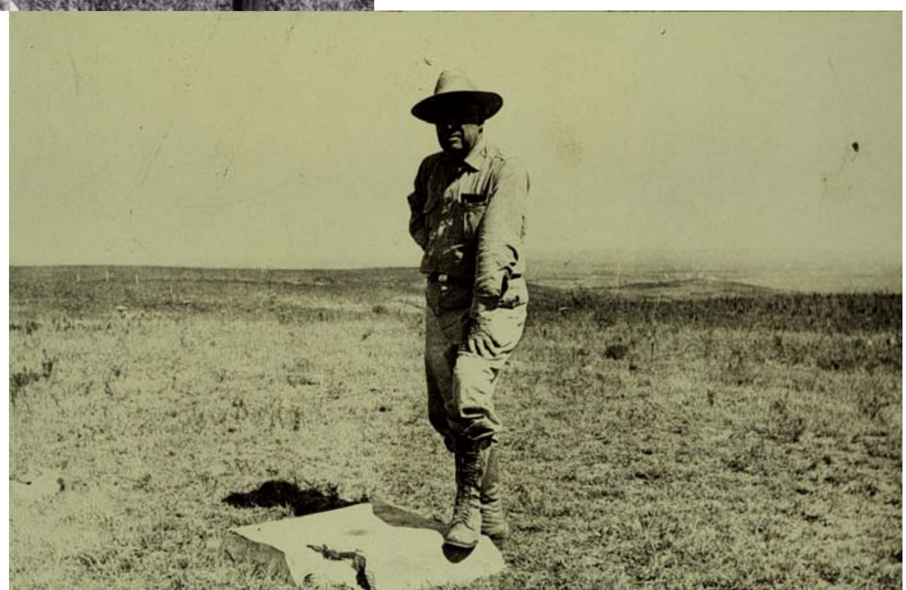


Figure 3

Figure 4

Station MEADES RANCH in Kansas

Additional surveys to densify the positions available in the network continued at an ever accelerated pace with newer equipment and motorized transportation. By the 1920s, it became clear that the addition of all this data would necessitate a recomputation of the positions and so in the period from 1927-1932 this was done. The computations were done manually and called the North American Datum of 1927 (NAD 27). The ellipsoid remained the Clark Ellipsoid of 1866 and the MEADES RANCH mark remained the datum point. See Figure 5 showing the Horizontal Network in June 1931.

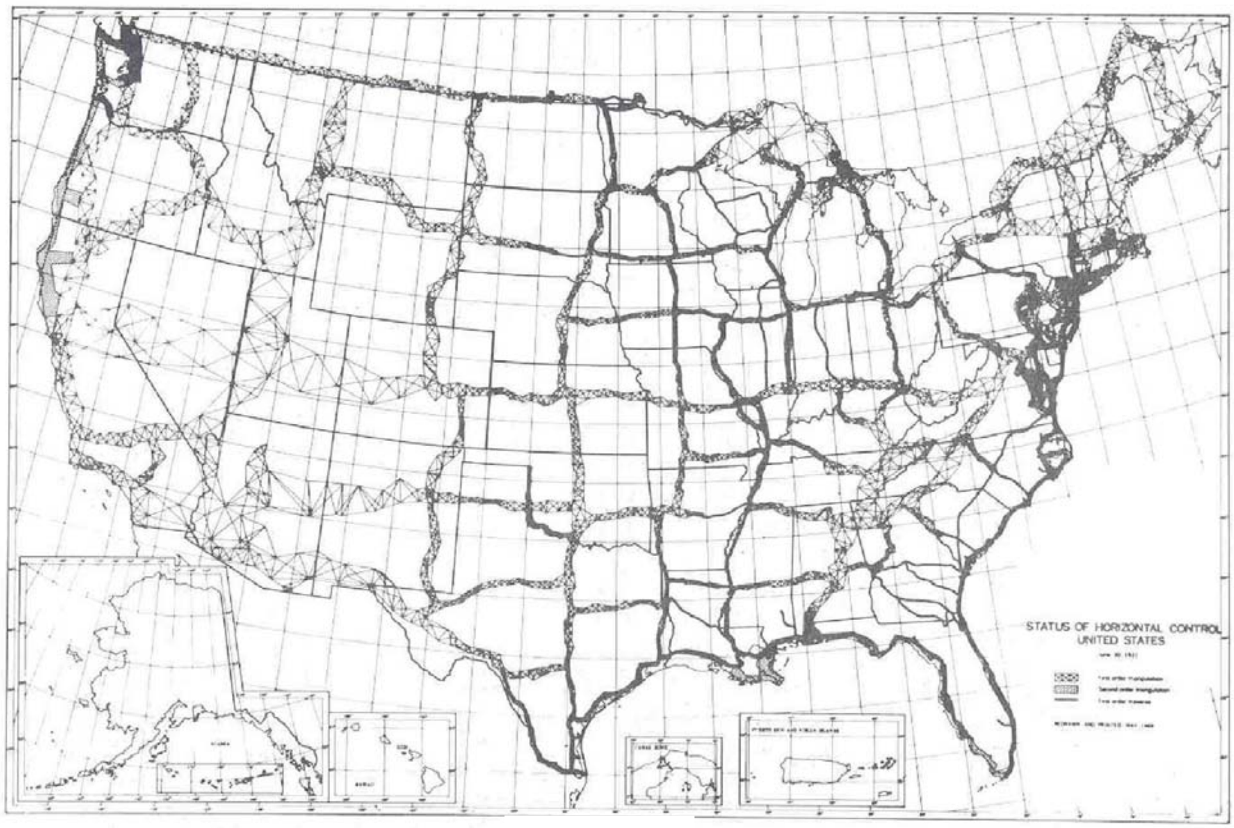
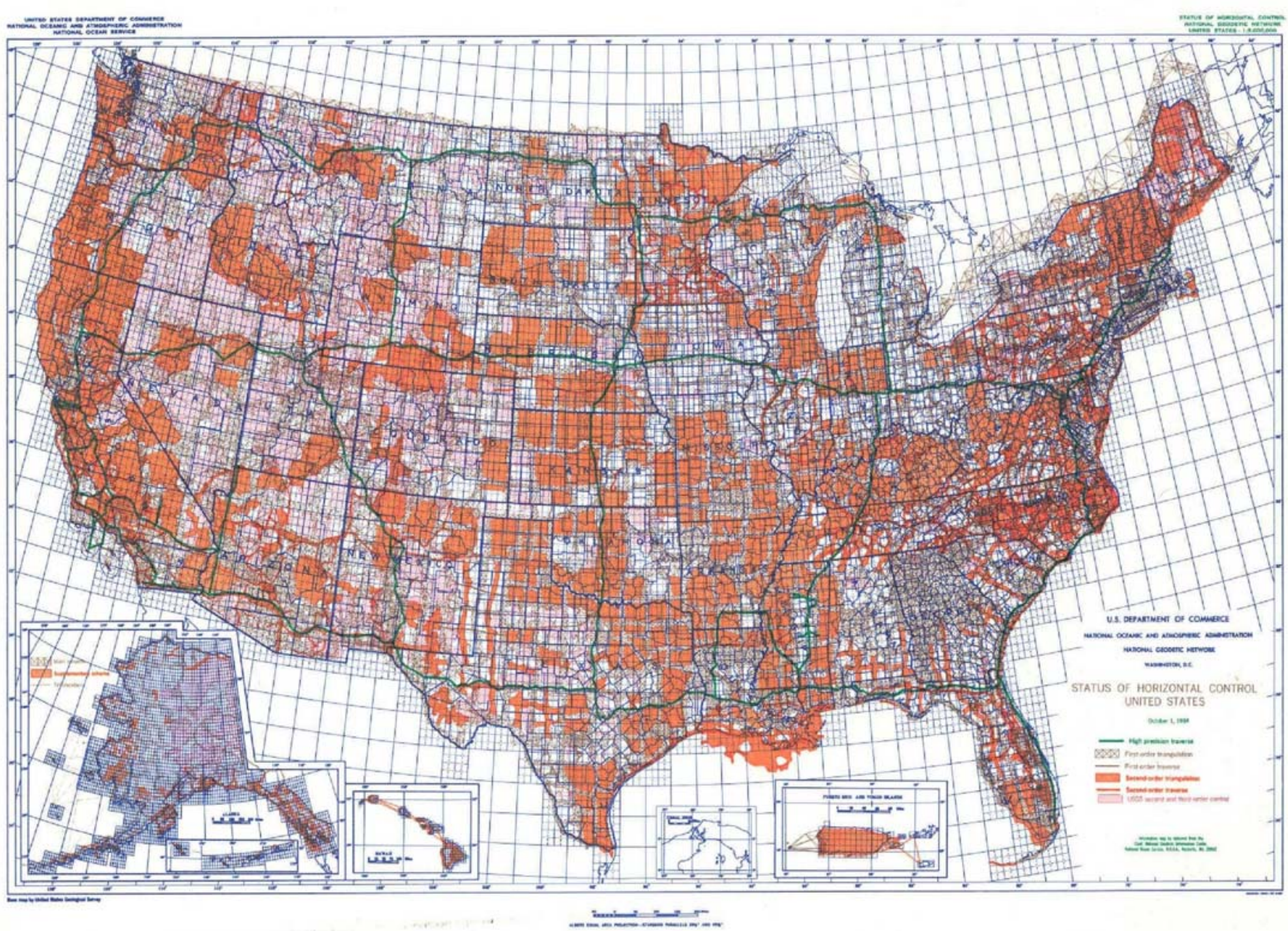


Figure 5

Although there were problems with the 1927 computation (e.g. sparse astronomic and gravity measurements, few ties to Canada and none to Mexico, and a 10 meter error in northern Michigan which had to be corrected), this massive hand computation served the country well in the years up to and including the 1960s. At that time however, electronic distance measuring equipment was introduced and it quickly became clear that the substantially increased accuracy possible with these measurements was not supported by the existing positions. The decision was made to not only recompute the positions of all the existing geodetic control points, but also to redefine the ellipsoid and the datum point and to digitize the observational data to be used, which would allow the use of computer technology for the computations. The Geodetic Reference System 80 (GRS 80)-an earth centered ellipsoid already in use for satellite based computations-was chosen, and the mass center of the earth became the datum point. Advances in technology, e.g. satellite observations, eliminated the need for the datum point to coincide with the surface of the earth. Methods were available to compute the differences between the surface of the earth and the ellipsoid at any point. Beginning in 1974 and continuing for the next 12 years, data from the observational surveys which had taken place from the 1800's (excluding some early surveys which were not of sufficient accuracy to be included), were digitized, checked and analyzed, involving during this period over 300 people and costing more than $37 million. See Figure 6 showing the Horizontal Network in 1984.



At this point, NGS embarked on one of the biggest computer tasks ever undertaken-the simultaneous algebraic solution of nearly 1,000,000 equations. The method used had been proposed by F.R.Helmert in 1880 but never applied by him. It was used in the adjustment of the European triangulation in 1950 and then, later, computer software had been written for its application. Still, it had never been used on so massive a scale. It proved to be an ideal way of solving all the equations simultaneously by dividing the data into blocks to expedite the task. The project was completed in 1986 and new positions were published for the 300,000 points it included.

The completion of the NAD 83 project ushered in the next substantial advance in technology-GPS. Very quickly it was realized that this new method of obtaining survey observations produced much more accurate results than the classically observed network positions would support, even after the massive re-computations just completed. As new GPS projects were completed, state and/or regional re-computations were necessary to upgrade the network so that the new GPS survey results would not be distorted or downgraded. This piecemeal pattern of re-computations has led to the decision to once again recompute all positions in the network. This time no new datum will be established (i.e. the ellipsoid will be GRS 80 and the datum will still be NAD 83). This recomputation is currently underway and it is anticipated that it will be completed in February of 2007-just in time to celebrate the 200th anniversary of the agency! [Editor's note, this work was completed in 2007, for information see: http://www.ngs.noaa.gov/PUBS_LIB/NSRS2007/FinalReports.shtml.] The Helmert Blocking method of simultaneously solving all the equations is being used, although the software has been rewritten and the computers used to do the computations are many times faster than those used for the original NAD 83 computation project.

However, since NGS is looking to the future, positions will simultaneously be computed in NAD 83 and in the reference system used by the GPS satellites-the International Terrestrial Reference Frame (ITRF). Currently this system is used for computing the orbits of the satellites which transmit the GPS signal to the receivers on the ground but coordinates which are produced are transformed to NAD 83 (the legal datum in the United States). As GPS becomes more widely accepted as the method of providing positions in many aspect of everyday life, using a system based on the system of the satellites directly will almost certainly become desirable. Then it is predicted that there will be demand for another change in the established datum in North America and the cycle of changing the datum to provide more accurate and useful coordinates will one again be necessary as will the recomputation if the positions of all the points..

Sources and suggested reading:

Basic Geodesy, NOAA reprint of Department of Defense, Defense Mapping School, student pamphlet

Impact of North American Datum of 1983, Elizabeth Wade, presented at ASCE Convention, Denver, CO 1985.

North American Datum of 1983, NOAA Professional Paper, NOS 2, Charles R. Schwarz, editor

North American Datum, A report by the Committee on the North American Datum, National Research Council, National Academy of Sciences, 1971

The New Horizontal Control Datum for North American, NAD 83, Steven A Vogel, 1986

www.seds.org/messier/Xtra/Bios/bessel.html (a short biography of Friedrich Wilhelm Bessel)