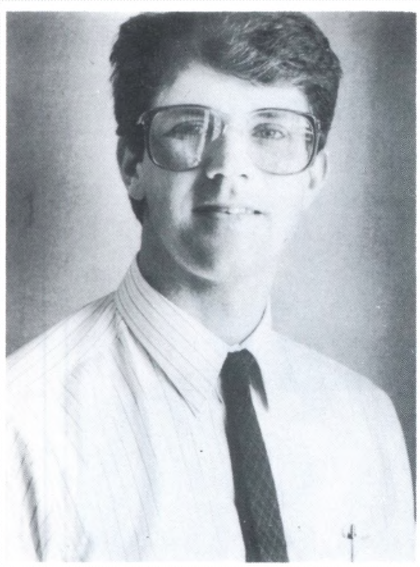
The Geodesy Corner

AZIMUTHS - GRID, ASTRONOMIC AND GEODETIC



BY JAMES FERGUSON

Several years ago, I was party chief for a boundary retracement project that involved survey observations derived from several survey methods. One of the data sources was the Global Positioning System (GPS), the second was conventional traversing using a local coordinate system, while the last was a series of astronomic observations taken at each of the points that had been established using GPS. The aim of the preliminary survey was to tie found evidence together using GPS, then calculate final lines without having to run trial lines. Since the original surveys were well over 100 years old, evidence was skimpy at best.

The field observations proceeded well, and data from each of the survey methods closed to within tolerances. Everything seemed fine until the time came to integrate all the information into one coherent system. This compiled coordinate data was to be used to compute inverses for the azimuths and distances of the final lines to be cut. Since each of the survey data sources have their own systems of reference, the data was not readily interchangeable. As a result, some of the survey problems that had to be overcome were caused directly by the significant differences between three types of azimuths - Grid azimuth, Geodetic azimuth and Astronomic azimuth.

In the last Geodesy Corner, we discussed the basic relationships between reference ellipsoids, the geoid, and datums. Our discussion of azimuths follows closely on the heels of these.

An azimuth can be defined as the angular measure between a predefined origin measured clockwise to a point. The line created between the point of observation and an observed point will assume an azimuth equal to the angular measure. Depending on whether the azimuth is grid, geodetic or astronomic, the origin differs. In the case of an astronomic azimuth, the origin is what is termed "true" north. This is the north that very closely approximates the meridian passing through the spin axis of the earth. For a geodetic azimuth, the origin is the meridian passing through the rotational axis of the reference ellipsoid in question. Finally, grid azimuths are referred to what is known as "grid" north. Grid azimuths are generated from map projections (Universal Transverse Mercator or UTM, for example) which represent the curved earth as a flat plane over relatively small areas. Grid north is a straight line as opposed to a meridian, and as such is useful only within the area represented by the map projection.

For a line to be oriented to a desired form of azimuth, it is necessary to know the coordinates of the two points forming the line. An inverse can then be computed using the coordinates in an appropriate formulae, and an azimuth derived. The type and accuracy of the coordinate information may vary with the observational method and the accuracy required in the final azimuth. For instance, a solar observation with a desired azimuthal accuracy of half a minute, may only require knowledge of the observing station's latitude and longitude to within several seconds. A grid azimuth with a required accuracy of several seconds will require coordinate information on the centimetre level. It follows then, that the origin of the coordinate information is the key to the determination of the azimuth of a line, not only as a matter of accuracy, but as a matter of the coordinate system itself.

The coordinate system used to define and determine astronomic quan-

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tities is one which is related to the physical earth, or the geoid. Astronomical observations are made with reference to the vertical at the point of observation [Bomford, 1971]. The vertical is also known as the normal to the geoid, or the plumb line. Of the three axes of the coordinate system used to reference astronomic quantities, one parallels the spin axis of the earth, the second is in the plane of the Greenwich meridian, and the third is at right angles to the second. The astronomic latitude and longitude of points in this system are defined using angles referenced to the equator and the axis of rotation of the earth respectively. The astronomical azimuth then, is the angle between two planes - one which passes through the observing station and the rotation axis or "true" north, and the second which passes through the observing station and a second point being observed.

Geodetic quantities are those in a coordinate system referenced to a mathematical framework we know as an ellipsoid. The three axes of this coordinate system fall, respectively, parallel to the "north pole" of the ellipsoid, in a plane akin to the Greenwich meridian, and at right angles to the second. It is impossible to "observe" geodetical quantities of latitude and longitude, because any observations we do are affected by gravity. Geodetic coordinates must be computed with respect to the vertical as it passes through the ellipsoid. This is often referred to as the normal to the ellipsoid. A geodetic azimuth can be defined as the angle between two planes - one of which passes through a point and the north pole of the ellipsoid, and the second which passes through this same point and a second point.

The fundamental difference between an astronomic azimuth and a geodetic azimuth is a function of the difference in the direction of the verticals which pass through any given point. This difference in the direction of the two distinct verticals can be expressed in terms of an east-west component, and a north-south component. These components are called the deflections of the vertical. Together they combine to form what is known as the Laplace correction. This correction can vary from the sub second level to a maximum value of about twenty arc seconds. Monitor stations are set up throughout North America to derive the Laplace correction at discrete points. The value from any given station can be used within a specified radius of the station. The correction doesn't vary greatly in a local area unless the terrain is quite mountainous. For much survey work, the difference between astronomic and geodetic azimuth is negligible, and is often ignored.

Grid coordinates, and hence grid azimuths, can be defined by many different systems. These systems are known as map projections, whose usage depends on a number of things, such as the survey requirements, and the region where the survey was done. Map projections aim to deal with the representation of a curved surface - the ellipsoid - onto a flat surface or plane - the map. Each representation is an attempt to minimize the distortion between the "real" earth and the map. With the diversity of map requirements throughout the world, it has been convenient for certain regions to utilize different map projections. Map projection types have unique qualities, depending on the mathematics used to derive the particular projection. For instance, a conformal map projection has the quality of maintaining angular integrity between the ellipsoid and the map. An equal area projection performs the task of keeping the mapping area the same between the ellipsoid and the map.

Many other types of map projections are in common usage. Some are specific applications of more general projections having similar properties. In Canada, the more common types of map projections are the UTM projection, the Transverse Mercator (TM) projection and variations of these two.

It is apparent when we think of projecting a representative curved surface onto a plane, that the direction of the azimuth origin - the north point - changes. Let us visualize a meridian being straightened out and fixed to a square plane surface which has been stuck onto the surface of the earth. If this square plane is oriented with the edge of the square running north-south (toward "true" north for instance), then the straightened out meridian will run diagonally across the plane surface. Let us call the direction of the edge of the plane "grid" north. Obviously there is an angular difference between the meridian line and grid north. This is what is known as the mapping angle, and is essentially the difference in orientation between a geodetic azimuth and a grid azimuth. Herein lies the problem with computations in which geodetic coordinates are mixed with map projection coordinates or grid coordinates.

It is important to note that grid azimuths can vary from geodetic and astronomic azimuths by up to a degree of arc. This difference can cause untold problems if not accounted for in the computations. One way of avoiding problems in the use of geodetic, astronomic and grid azimuths (and ultimately coordinates) is to pick one system and stick with it. There are many reference books which give the mathematical relationships between these systems, and numerous computer programs that make transformations extremely easy and efficient. For example, a survey whose orientation has been determined by a meridian derived from an astronomic azimuth, can be transformed entirely into a grid coordinate system. Computations of grid distance and azimuth can then be used for future survey work within the project area.

For now, keep bearing with those azimuths, and have a good new year.

Next time in the Geodesy Corner - "What is Height Anyway?"

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