National Spatial Reference System Readjustment of NAD83

Chris Pearson
NGS Geodetic Advisor for Illinois
2300 S. Dirksen Pkwy.
Springfield, IL. 62764
Chris.Pearson@noaa.gov

Abstract

The National Geodetic Survey is responsible for the establishment and maintenance of the National Spatial Reference System (NSRS). As such, our goal is to maintain a network of stations which are of high enough accuracy to serve as control for any project undertaken by local surveyors. In addition, numerous other applications benefit from an accurate, consistent coordinate system. The NSRS serves as the framework for those also. As the Global Positioning System (GPS) became operational in the early 1990's, NGS quickly realized the possible increased accuracies of the coordinates and undertook a series of GPS surveys to establish High Accuracy Reference Networks (HARNS) in each state to serve as the basis for the NSRS. These were completed in 1998. In addition, by the mid-1990's, the establishment of the network of Continuously Operating Reference Stations (CORS) was begun which made even higher accuracies possible. So, in 1998, NGS undertook yet another series of observations in each state designed to tie the network to the CORS and to realize the advances in surveying with GPS which allowed increased accuracies in the height component - long a weak link in the framework. These surveys are now complete (December 2004). The availability of this high accuracy data, along with substantial growth in the NSRS due to the addition of local GPS surveys to the network, has resulted in a need for a national simultaneous readjustment which utilizes all these observations. Although NGS has strived to maintain a consistent network, inevitable discrepancies between surveys and between states have taken place. Such a readjustment, using all available GPS data archived in the NGS database, also allows for the computation of local and network accuracies for each mark. This readjustment is scheduled to begin in June of 2005 and be completed in February of 2007.

Introduction

The readjustment of all GPS survey control in the United States is being undertaken by the National Geodetic Survey and expected to be completed by 2007. The adjustment has been developed for two major reasons. The first of these is a requirement stated in the Federal Geographic Data Committee (FGDC) Draft Geospatial Positioning Accuracy Standards (FGDC 1998) to develop individual local and network accuracy estimates for each point in the network. The second purpose for the readjustment is to resolve inconsistencies between the existing state wide HARN adjustments and the nationwide CORS system as well as between states. The purpose of this paper is to update the survey community on the reasons for the readjustment, the general timeline that the readjustment is expected to follow and the methodologies that the readjustment will use.

History of adjustments in NAD83

NAD83 was implemented in 1986 with a complete readjustment of all available survey data to establish a uniform set of coordinates for all points in the network based on an earth centered ellipsoid. Unfortunately, with the advent of GPS shortly after the completion of the 1986 adjustment, the local accuracies of points included in this adjustment were found to be too low to support the new satellite based techniques. In order to remedy this problem quickly, a series of GPS surveys called High Accuracy Reference Networks (HARNS) were conducted in each state starting with Wisconsin in 1989 and followed by readjustments of all survey data available (GPS and classical) in each state. These surveys and subsequent readjustments produced a set of coordinates with much improved local accuracies. However, the situation was again complicated with the establishment of the Continuously Operating Reference Stations (CORS) network in the mid-1990's. Once again statewide high accuracy GPS surveys were conducted in each state to tie the HARN network to the CORS and, in addition, to take advantage of advances in GPS technology which resulted in much improved ellipsoid heights. Subsequent statewide readjustments have also been undertaken as required (including all the GPS data available in the state only). All these readjustments, only undertaken on a statewide basis and limited to inconsistencies greater than 5 cm, have resulted in consistency problems across state lines. In addition, public demands for greater than 5 cm accuracy in the positions and heights contributed to NGS's decision to undertake a national readjustment. The availability of this high accuracy data and the need to implement the local and network accuracy standards suggested that the time was right for a new National Readjustment and on September 24, 2003, NGS's Executive Steering Committee approved a plan for the readjustment of horizontal positions and ellipsoid heights for GPS stations in the contiguous United States. Some of the key points are:

1. Only GPS will be adjusted. Classical geodetic observations will not be included.
2. The CORS stations will serve as control, ie, CORS positional coordinates will be held fixed.
3. The FBN/CBN surveys are a key element since these are high accuracy (2 cm) surveys that tie the traditional geodetic marks from the HARN network to the CORS throughout the contiguous United States.
4. A Helmert Blocking strategy will be used for the adjustment.
5. Both NAD 83 and ITRF coordinates will be produced and published. The former will be designated *NAD 83 (NSRS)*.
6. User densification projects will be included if observed with GPS, tied to the HARN network and submitted prior to the June 1, 2005 deadline.
7. Projects submitted after this date will be accepted and loaded into the database with a datum tag reflecting the most current HARN adjustment available for the state. These projects will be readjusted to reflect the new national readjustment as soon as possible after its completion in 2007.
8. Network and local accuracies will be implemented with the Readjustment of the National Spatial Reference System (NSRS).

9. In the event of a delay in software development, testing, and implementation of the new network and local accuracies, a contingency option was adopted. This option endorses immediate statewide GPS readjustments of both horizontal positions and ellipsoid heights; local and network accuracies would not be produced. (Implementation of this contingency is not currently anticipated.)

Local and Network accuracies

As noted above, the changes in the way the accuracies of geodetic positions are published were defined by the FGDC:

> "Local and network accuracy measures computed by random error propagation determine the provisional accuracy. In contrast to a constrained adjustment where coordinates are obtained by holding fixed the datum values of the existing network control, accuracy measures are computed by weighting datum values in accordance with the network accuracies of the existing network control."

This has been interpreted to mean that the local and network accuracies are determined by the mean of the principal axes of the absolute and relative coordinate error ellipses respectively. Unfortunately, as discussed below, neither of these quantities can be calculated for control points in the North American network without a full readjustment of all of the underlying survey data.

Local and network accuracies are two measures which express to what accuracy the coordinates of a point are known. Network accuracies define how well the absolute coordinates are known and local accuracy defines how well the coordinates are defined relative to other points in the network. These quantities will be computed from error ellipses, which are graphical representation of errors associated with adjusted coordinates. They represent the region about the computed position of a station where there is a particular probability (confidence interval) that the station is actually located. They are characterized by orientation and size of the principle axes and the size of the principle axes will increase with a decrease in confidence. There are two basic types of error ellipses. Absolute error ellipses represent how well coordinates are determined relative to the datum and relative error ellipses represent the errors in the relative position between two points. They can be calculated from the off diagonal covariance matrix and can be defined regardless of whether observations exist between the points or not. Both types of error ellipses are calculated from the appropriate parts of the coordinate covariance matrix which can be produced only during a least squares adjustment. Because the covariance matrix for points within the NGS database is not currently available, a simultaneous national readjustment is required before local and network accuracies can be calculated.

In simpler terms, the network accuracy of a control point is a value that represents the uncertainty of its coordinates with respect to the geodetic datum at the 95-percent confidence level. Since the datum is considered to be best expressed by the Continuous

Operating Reference Stations (CORS), which are held fixed during the adjustment, local and network accuracy values at CORS sites are considered to be infinitesimal (approach zero). The Local Accuracy of a control point is a value that represents the uncertainty of its coordinates relative to other directly connected, adjacent control points at the 95-percent confidence level. This value represents the relative positional error which surveyors can expect between survey marks in a locality. It also represents an approximate average of the individual local accuracy values between this control point and other observed control points used to establish its coordinates although, in general, all of the immediately surrounding stations will not necessarily have been used in the survey which established the original coordinates. These accuracies will be implemented with the National Readjustment.

Helmert Blocking

Helmert blocking, which was developed a little over 100 years ago by F. R. Helmert (Helmert 1880) is basically a technique for breaking up a least squares adjustment problem, which is too large to be managed as a single computation, into many smaller computational tasks with potentially large savings in computer storage and CPU requirements. While several other strategies exist for dividing a large survey network into manageable sized pieces for adjustment, the method of Helmert Blocking has the crucial advantage of producing not only a set of coordinates that will work together, but also a complete covariance matrix relating errors in each coordinate in the network to every other coordinate.

Helmert blocking starts by dividing a survey network into a series of subnets or blocks. The requirements for dividing survey data into blocks are fairly simple. Each observation must be included in one, and only one, block. In conventional surveying, each observation can be assigned to a block fairly arbitrarily, however, in GPS measurements, the situation is more complex because each simultaneously observed GPS baseline has in principal, nonzero covariance terms with every other baseline observed at the same time. If these off diagonal co-variance terms are preserved, as they are for all sessions processed using the NGS vector reduction program PAGES and other advanced GPS processing packages, then all of the baselines observed during a session must be assigned to a single block rather than being partitioned between blocks. This occurs because in session processing, all baselines processed from the GPS phase data from all of the GPS receivers logging at a given time are in effect a single observation.

Division of survey data into blocks is, perhaps the key step to developing a successful adjustment using Helmut Blocking. Generally blocks are based on some criterion such as survey order (for example FBN/CBN surveys vs 1st order UDN surveys) or geographically (for example all surveys within an individual state). Within each block, the unknowns (ie coordinates) are divided into junction unknowns (ie those that have some observation connection with neighboring partial nets) and inner unknowns (which have no observation connection outside the block).

For the national readjustment, North America will be divided into a series of regional blocks with one block per state, one for our neighbors Canada (and perhaps Mexico and one for the Caribbean data available from the airport survey there). Each block will include all of the data GPS based surveys submitted to NGS within these regions with the exception of data which, due to its timing or quality would not contribute to the success of the readjustment. Currently 149 Projects with 9903 stations are not recommended for inclusion. These include:

1. Many Third Order FAA Projects from 1980's
2. Some Projects that have no ties to the Network
3. Original TN HARN (Macrometer Data)
4. Original Eastern Strain Network Project

Once all the normal equations of each of the blocks have been formed and adjusted, they are reassembled using the back solution to give a full homogeneous solution for all coordinates in the network and a full covariance matrix. The covariance matrix is a very important result as it provides the method for calculating relative accuracies and thus satisfying the requirements for reporting accuracies within the FGDC guidelines.

Weighting

One of the most important requirements for the procedure to be successfully concluded is a uniform set of weights that will reflect the relative accuracies of the disparate sources of survey data included in the national readjustment. In order to accomplish this, projects are adjusted individually, checked for blunders and weights determined for the horizontal component and the vertical component of the project observations. Since only GPS data will be included in the adjustment, the network is reasonably homogeneous, and determining a realistic set of weights is not considered to be a major problem.

Datum issues

The adjustment involves two different datums. The first of these is the International Terrestrial Reference Frame (ITRF). Its origin is at the center of mass of the whole Earth, including the oceans and the atmosphere. The datum is updated periodically each time there is a new origin, most recently with ITRF2000. The ITRF approximates the NUVEL1 NNR or no net rotation reference frame where plate motions average globally to zero. Plate tectonic movement is accommodated explicitly by giving each point a coordinate at a reference epoch and a velocity vector that reflects the future trajectory of the point with time.

NAD83 is similar to the ITRF datum in that it has the same earth model (or ellipsoid) and a similar origin (Snay and Soler 2000). However points that fall on the stable North American Plate (which covers most of the 48 contiguous states) have coordinates that are fixed in time. Points in the far west of the United States which lie on the boundary between the North American and Pacific plates do have velocities that are provided by the NGS utility HTTP.

Because of the difference in the way plate tectonic velocities are treated in the two systems, the difference between them is slowly changing. Transformations between NAD83 and the various ITRF realizations are periodically updated (Craymer, Milbert and Knudsen 2001)

Coordinates will be produced and published for both NAD83 (NSRS) and ITRF. At this stage, we plan to conduct the adjustment in NAD83 and use published transformations to derive values in the ITRF afterward. We have chosen this methodology because the ITRF requires velocity vectors for each point, while the NAD83 datum is referenced to the stable part of North America. Since stable North America moves in the global reference frame due to plate tectonics, each point in the adjustment would require a velocity vector to be adjusted in the ITRF. The NGS utility HTTP can provide the required velocity vector by extrapolating velocity vectors from areas where measured vectors exist. However since most of the points in the NSRS network are located on the stable North American plate, this step is unnecessary if the adjustment is conducted in the NAD83 datum. HTTP is used for points on the far west of North America which straddle the divide between the North American and Pacific plates.

Policy

The Readjustment of the NSRS is scheduled to commence in June 2005 and is scheduled for completion February 10, 2007. Because a Helmert Blocking strategy will be used, all projects which will participate in the readjustment must be loaded in the National Geodetic Survey Database prior to its commencement. Hence, a cutoff date of June 1, 2005 will be required for submission of all projects to allow for review and loading in the database. Any project submitted after that date will be loaded in the database and published but not included in the adjustment.

Conclusions

The readjustment of all horizontal survey control in North America is being undertaken by the National Geodetic Survey with an anticipated completion in 2007. This readjustment will have three important results for surveyors working in the United States. First, all survey points in North America will have a single adjustment tag in contrast to the current system of HARN adjustments where most states are adjusted individually producing a bewildering number of adjustment tags. Secondly, it will remove any residual differences between NAD83 (CORS) positions which are produced by the NGS OPUS (Online Positioning User Service) facility and the various HARN adjustments used by the various states. Thirdly it will allow implementation of FGDC standards requiring each station to have individual estimates of local and network accuracies. Because implementation of the local and network accuracy standards require an estimate of the covariance matrix obtained from a simultaneous solution, the adjustment will be conducted using the Helmert blocking technique.

References

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