national readjustment of 2007

In 1986, NOAA's National Geodetic Survey (NGS) completed the first general readjustment of all its horizontal data holdings in 50 years. This task involved 14 years of digitizing data, writing software, setting up a database and many hours of computer time. The data included in this task consisted mainly of the classical triangulation and trilateration observations covering the 180 years of the agency's existence. In addition a new Earth centered ellipsoid and a new datum were defined for the reference frame for this adjustment. The datum was given the name NAD 83(1986) and replaced the existing datum (NAD 1927) as the official datum of the U.S. Government.

But new technology was already being developed which was more accurate than anything done previously. Almost as soon as the readjustment was complete, it became clear that the newly determined coordinates would not support the accuracy needed for the National Spatial Reference System (NSRS) to serve as the control for any survey undertaken using GPS(Global Positioning Service) equipment. This new

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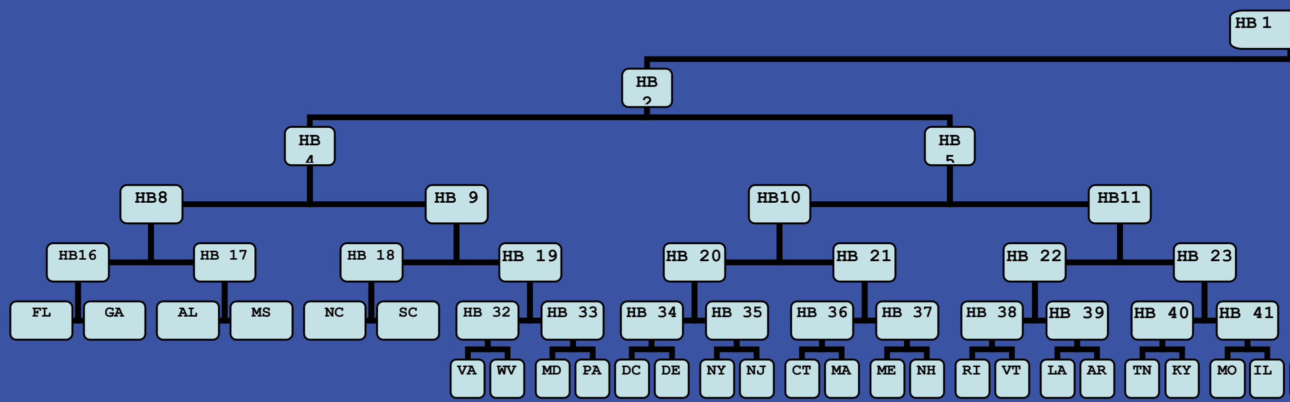
helmert blocking strategy

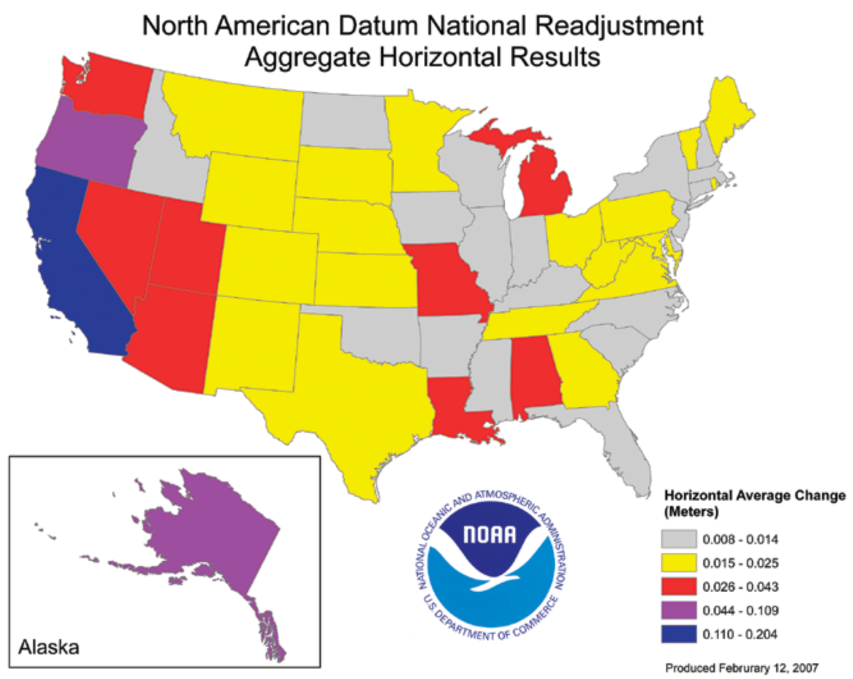


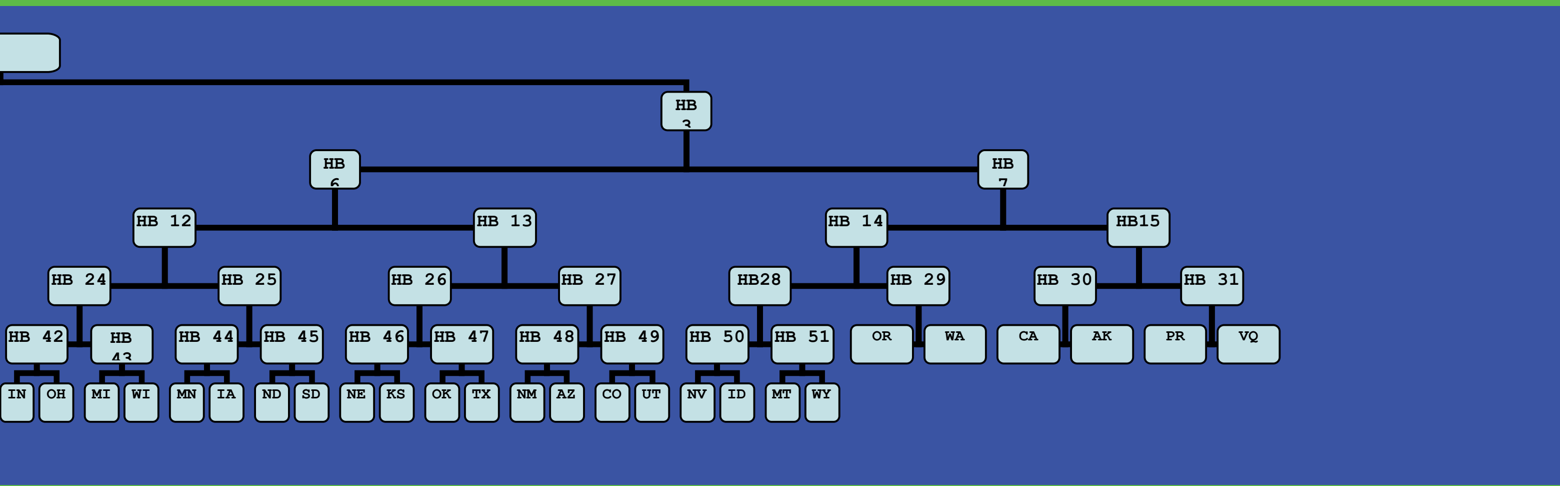
GPS technology revolutionized the way geodetic surveys were done even more than the introduction of electronic distance measuring equipment two decades earlier.

Therefore, beginning in the late 1980s and for the next 20 years, NGS collected new data-generally state by state-using GPS technology. However, as with the observations that comprised the network at the time of the NAD83 (1986) adjustment, this GPS network was built up project by project, not necessarily in a cohesive, straightforward fashion. And, as with NAD27, distortions inevitably resulted. For example, after about a decade of GPS surveys, the Continuously Operating Reference Station (CORS) network came into existence providing another level of accuracy for the geodetic control. Indeed, regional readjustments have been necessary twice in most states since 1986 to accommodate the ever increasing accuracy of the observations and computations.

Despite efforts to keep inconsistencies to a minimum, one adjustment was needed to eliminate what was becoming a logistical problem – publishing accurate, consistent coordinates for all stations in the network without constantly readjusting parts of the network. Additionally, providing local accuracy (the accuracy between adjacent directly connected points) and network accuracy (an accuracy relative to the CORS control) estimates for each point had been mandated by the Federal Geographic Data Committee (FGDC) Draft Geospatial Positioning Accuracy Standards (FGDC 1998). These values for existing points are best computed by a simultaneous adjustment which includes all the observations available. Accordingly in 2003, a comprehensive plan was laid out and approved for a general readjustment of the horizontal positions and ellipsoid heights of all GPS-observed marks in the NSRS. The Plan called for including only the GPS observations and was not to include a readjustment of orthometric heights. Tests indicated that changes to the coordinates of the classically observed stations would be insignificant due to earlier regional readjustments which had included all classical stations.

To accomplish the previously mentioned regional readjustments (usually statewide), NGS used a method of 'layering' in which a dataset consisting of the highest accuracy observations (predominately from A-order projects) would be adjusted together using CORS (or their predecessors) for control. This was layer one. The second layer of data contained the next highest order of accuracy projects (usually B-order) holding fixed the results of layer one.



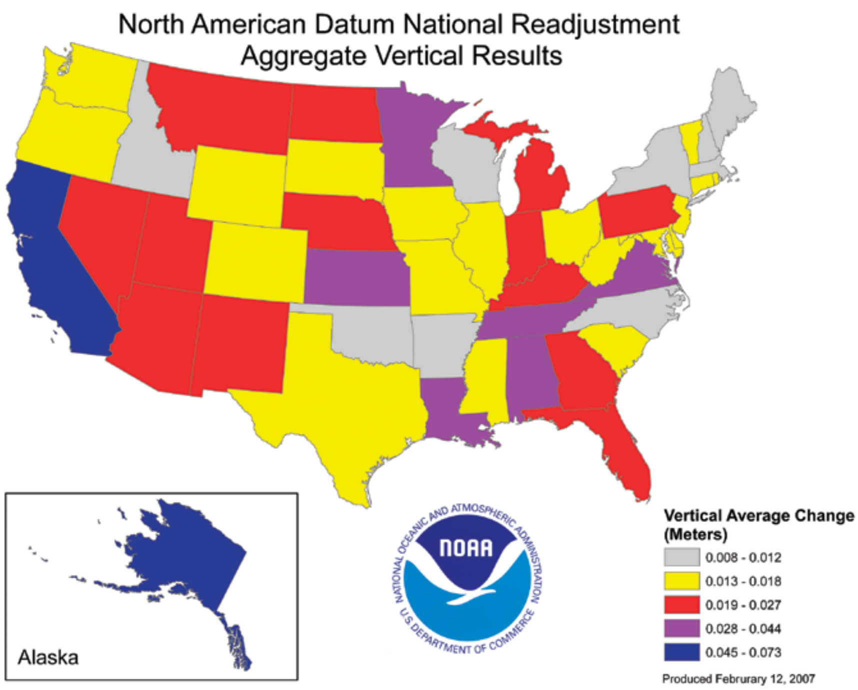


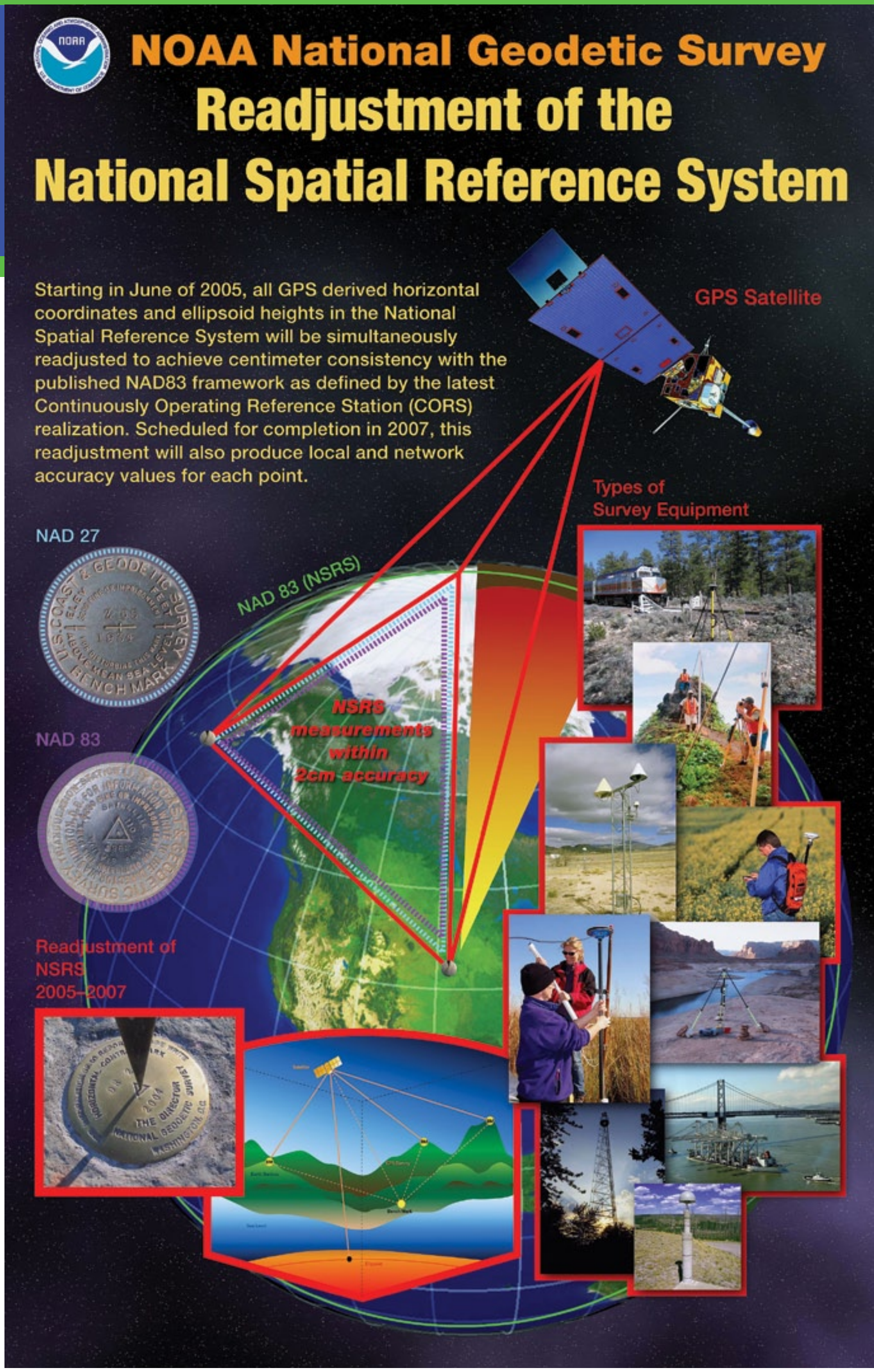
This process continued down to the lowest layer containing the least accurate data-each time with the coordinates from layers already completed serving as control. This method worked well and generally resulted in accurate, consistent values for the coordinates commensurate with the accuracy of the projects in the particular layer. The problem was that this was done state-by-state building up the new coordinates in a piecemeal fashion which resulted in discontinuities at the boundaries of states where projects crossed state lines.

Despite this, it was initially thought that a modification of this type of adjustment could be used to carry out a nationwide readjustment. The advantages would be using a known, tested method and using existing software. However, one major problem emerged. Tests indicated that the proposed method of layers combined with running dual adjustments-one to get coordinates, one to get the accuracies-did not produce valid accuracies. A second problem was encountered; after the first or second layer, the country would have to be broken up into regions for the remaining layers and time estimates optimally put the completion of the readjustment in late 2007.

It was therefore decided to use the Helmert Blocking method for the readjustment. Some in-house software already existed which could be modified to form the basis of the computations; additional software would be developed through contracting. The advantages were that this method had been used for the 1986 readjustment and that it would produce acceptable estimates of the local and network accuracies. It also would result in completion of the entire project at the same time instead of sequentially over a period of two years with partial results published periodically over that period.

Helmert Blocking is basically a technique for computing a simultaneous least squares adjustment of a large data set by grouping the data into smaller pieces, called 'blocks', and producing the complete covariance matrix used in calculating the local and network accuracies. For this adjustment, the blocks were named by state and every GPS project was assigned to a specific state block. This resulted in some data collected in one state appearing in another state Block but prevented splitting sessions of observations and minimizing junction points. Blocks are combined two at a time, reducing the number of station coordinates to be estimated to only those stations that are associated with GPS observations belonging to other blocks. Eventually only one block remains and a solution for the coordinates of its stations can





be performed. Then a back solution is run to solve for station coordinates for all the intermediary blocks. Stations are identified as junctions if they are associated with observations which fall into more than one block. The CORS serve as control and they are all identified as junctions whose positional coordinates are constrained to their published values at the top level before the back solution.

Clearly, the GPS data set now comprising more than 20 years of observations has a wide range of data accuracy. Unlike the layering method of combining the observations, all the data is combined in what is essentially one layer, so the weights assigned to these observations is especially critical. To address this issue, all GPS projects which were to participate in the readjustment were retrieved individually from the database, a free adjustment was run, the results checked for blunders and outliers and two scaling factors determined for the GPS derived vectors that represent the three-dimensional coordinate differences between stations-one for the horizontal component, the other for the vertical component. A simple formula was used for these factors. Based on experience reported with the CORS and analysis of the nearly 5000 GPS projects over the past 20-year period, the horizontal component was given twice as much weight as the vertical component. These factors were loaded in the database and applied to the project vectors upon retrieval for their specific Helmert Block.

In 2004, NGS established a cut off date of June 1, 2005 for receipt of any project which would be guaranteed to be included in the readjustment. So many projects were received on or near the deadline that it was not until November 2005, that all could be loaded in the NGS database. While this loading effort was underway, the software was finalized, two additional computers obtained for processing, methods of identifying junction stations determined, and a myriad of other small details were resolved. The free adjustments, once started, ran relatively smoothly and the work began of analyzing the vector residuals and position shifts.

As previously mentioned, the CORS coordinates serve as constraints for the project. The values currently published, *i.e.,* NAD 83 values transformed from ITRF96 (epoch 2002) will be used, except in states affected by crustal motion. There, tectonic movement over the 20 years of observations must be taken into account. Except in California, Horizontal Time Dependent Program (HTDP) software is used to apply corrections to bring the observations and control to January 1, 2007. In California, January 1, 2007 values supplied by the California Spatial reference Center (CSRC) were used. It had been anticipated that ITRF2005 coordinate values (transformed to the NAD 83 reference frame) would be available in time to form the basis for the readjustment but these were delayed to the point that it would be 2008 before these values would be published. In addition, the method of calibrating antenna phase center variations will be changed possibly making the vector data currently available incompatible with the new coordinates. Still, since the currently published coordinates of stations participating in the readjustment have been tied to CORS of different epochs, the new adjustment will bring them all to a common epoch.

The National Readjustment contains 67,708 stations with 302,171 vectors. The final constrained adjustment was completed on February 8, 2007 and results posted to the National Readjustment web page on February 9, 2007.

The new adjustment underscores NGS's continuing commitment to providing up-to-date, highly accurate control for all surveying needs in the nation.

An issue which arose prior to the completion of the computations was the naming of the Readjustment. The datum is not changing – *i.e.,* it will continue to be NAD 83. Past practice has been that as major state readjustments were completed, a date 'tag' would be added to the datum name (*e.g.,* NAD 83(1993)) to indicate the change to a GPS derived and controlled reference system. While this was helpful to distinguish coordinates determined in 1986 and those determined more recently, each state ended up with a datum tag date different from some or all of its neighbors. This led to confusion about whether stations with different dates could be considered consistent. To avoid this and to highlight the fact that this is a simultaneous National Readjustment of all GPS data in the NGS database, the initial proposal was to use NSRS (National Spatial Reference System) as a datum tag without any associated date, *i.e.,* NAD 83(NSRS). However, in response to concerns that this change was also confusing, a poll was taken through the National Readjustment website (www.ngs.noaa.gov/NationalReadjustment/) to solicit comments on this designation. The result is that a date will be added to the NSRS tag-i.e. the readjustment will be called NAD 83(NSRS2007).

Another issue to be addressed as a result of the National Readjustment is that of a datum transformation which can be applied to values previously computed relative to the HARN but not participating in the National Readjustment. This is expected to be a seven-parameter Helmert transformation which can be used for non geodetic control applications and will take into account the change in height as well as changes in latitude and longitude.

Projects submitted between November 15, 2005 and February, 2007 are not included in the National Readjustment but are included in the database and are currently being published. In the past, NGS' recommendation has been that, due to limited in-house resources for project readjustments after the readjustment, the project submitter readjust and resubmit the project to NGS with the new coordinates. But, due to significantly improved software which has been developed, another full readjustment, just to include these projects, may be feasible. This may not, however, be possible for some months after the National Readjustment completion and those wishing more immediate results are advised to perform their own re-adjustments.

An additional issue currently undergoing intense analysis is the method to incorporate and compute local and network accuracies in future individual survey projects. This issue is not resolved but several methods are being reviewed for accuracy and feasibility. Whatever method is chosen will be implemented with ease of use by the submitter while maintaining reliability of the results of primary concern. Policy will be announced on the NGS Web page and through seminars and workshops as quickly as possible.

Another by-product of the National Readjustment will be the publication of ITRF coordinates for all GPS stations in the NSRS. A major study of the issue of the future of the NSRS in the late 1990's concluded that there would be more and more demand for these ITRF values as real-time applications for GPS became routinely available.

In conclusion, the National Readjustment computations are complete and available through the National Readjustment web page pending the completion of the software for the data sheets. This has been an appropriate part of the commemoration of the 200th anniversary of the founding of the predecessor agency of the National Geodetic Survey by Thomas Jefferson on February 10, 1807. It underscores NGS's continuing commitment to providing up-to-date, highly accurate control for all surveying needs in the nation.

Maralyn Vorhauer is a geodesist serving as a technical advisor to the chief of the Observation and Analysis Division of the National Geodetic Survey. She serves as Project Director for the National Readjustment of the GPS data component of the Spatial Reference System. She also does the final quality review of all projects before acceptance by NGS and their inclusion in the NGS database. She has worked for the National Geodetic Survey and its predecessors since 1965 when she graduated from George Washington University in Washington, D.C. with a degree in math.