The North American Datum of 1983

A Collection of Papers Describing the Planning and Implementation of the Readjustment of the North American Horizontal Network

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American Association for Geodetic Surveying
Monograph No. 2

American Congress on Surveying and Mapping

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Datum of 1983

A Collection of Papers Describing the Planning and Implementation of the Readjustment of the North American Horizontal Network

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American Congress on Surveying and Mapping
210 Little Falls Street, Falls Church, Virginia 22046

SINCE the launching of space satellites (1957), geodesists and surveyors have increasingly grown aware of the deficiencies of the existing North American Datum of 1927. Although the existing datum and network generally satisfied lower order survey requirements for engineering and mapping, new applications for geodetic networks and the associated higher accuracy requirements demanded a new datum and network positions.

With the advent of electronic distance-measuring equipment, development of ultra precise portable timing equipment, development of information processing—data management systems, the use of satellite doppler ranging, and development of complex mathematical/statistical theories, it became imperative for recomputing and adjusting the U.S. network. Under the leadership of the Directors of the National Geodetic Survey, National Ocean Survey, National Oceanic and Atmospheric Administration (Captain Leonard S. Baker, Captain John O. Phillips, and Captain John D. Bossler), the National Geodetic Survey has led the effort to develop the requisite technology and procedures for the readjustment.

This monograph is a collection of articles by NGS personnel and others describing various aspects of the NAD 1983 program, which includes the geodetic agencies throughout North America and Greenland. These articles were originally published in the *ACSM Bulletin* between August 1975 and February 1982. Some minor changes to earlier published articles have been incorporated in this monograph. The American Association for Geodetic Surveying would like to thank Mrs. Eleanor Andree of NOAA and Mrs. Jane R. Kennedy of Kennedy Associates for their efforts in preparing this monograph for publication.

HERBERT W. STOUGHTON, PH.D., *Editor*
Chairman, AAGS Publications Committee

American Association for Geodetic Surveying
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Preface

THIS monograph is a collection of 26 articles on various aspects of the New Adjustment of the North American Horizontal Datum that were originally published as a series in the *ACSM Bulletin* between August 1975 and February 1982. Together these papers describe the methods being used by the United States and the other countries of North America to perform the largest geodetic network adjustment ever undertaken. When completed, the new datum will be known as the North American Datum of 1983 (NAD 83).

In the first article, it was stated that these papers would be authored by members of the National Geodetic Survey (NGS). Authorship was later expanded to include and acknowledge the work of other agencies and nations. As a result, four of the 26 articles were written by authors outside the NGS family. Article No. 10 was written by the late Professor Peter Meissl of the Technical University in Graz, Austria, based on a study he conducted under a visiting scientist program at NGS. Articles 18, 19, and 20 are status reports on the geodetic adjustment in the participating countries other than the United States. Hiram H. Skaggs, Jr., of the U.S. Defense Mapping Agency wrote the article on Mexico, Central America, and the Caribbean area; C. David McClellan of the Canadian Department of Energy, Mines and Resources, presented the status of the geodetic adjustment in Canada; and Frede Madsen of the Geodetic Institute in Copenhagen, Denmark, reported on Greenland.

The target level of comprehension and general purpose of the series were outlined in Article No. 1 by John D. Bossler, first project manager of the New Adjustment: "Every effort will be made to make these presentations easy to read and understand, with a primary purpose of informing the surveying community as to the problems and progress associated with the New Adjustment."

The publication of these articles as numbered members of a series devoted to a common theme—the NAD adjustment—could lead to false assumptions, followed by some small degree of disappointment. To forestall this possibility, a few words are in order on what this series is *not*. What the series *is* will then be obvious from a careful look at the Table of Contents and subsequent reading of the articles.

This is not a preplanned series. The articles do not follow any strict chronology, such as the order in which the constituent parts of the NAD system were and are being developed, or in which the adjustment is being performed. There are no articles dealing with the history and planning which preceded the New Adjustment, and there are no final articles which sum up the others and present conclusions. Neither are these articles pedagogical or tutorial, except incidentally. They were not designed to tell in any organized, detailed way how things are being done. Therefore, it is not necessary that they be read in any prescribed order, although some articles do make passing reference to earlier articles.

Article No. 26 is the last in this particular sequence but not necessarily in the series. Others may possibly be added in the future as the project nears completion and the final results are published.

Comments or questions should be directed to John G. Gergen, current project manager of the New Adjustment.

Table of Contents

The New Adjustment of the North American Datum

Reprinted from the *ACSM Bulletin*

Article No. 1

The New Adjustment of the North America Datum (Introduction)

by Commander John D. Bossler

Project Manager, NAD
National Geodetic Survey
NOS, NOAA, Rockville, Md.

A series of articles concerning the New Adjustment of the North American Horizontal Datum will appear in the *ACSM Bulletin*, which will be authored by members of the National Geodetic Survey (NGS). Every effort will be made to make these presentations easy to read and understand, with a primary purpose of informing the surveying community as to the problems and progress associated with the New Adjustment. Terminology which is not commonly used in plane surveying will be explained. For example, in this opening paper, "earth centered" is defined to be the center of mass of the earth and its atmosphere; "computer-readable" means that information has been placed on cards, tapes, or disks in a form compatible with the computer employed; "reference system" in this context implies that computations are performed on an ellipsoid with a specific orientation, although in future papers we may discuss Cartesian coordinate (reference) systems in three dimensions (x, y, z); and finally "observables" are measured quantities such as horizontal directions or angles, distances, astronomic azimuths, etc.

The kickoff day for the New Adjustment was July 1, 1974. An overview of the entire project will serve as the lead paper.

The adjustment will probably place every country considered a part of North America, (Denmark (Greenland) to Panama) on the same datum. That datum will be, to the best of our knowledge, earth centered and on a newly adopted reference system. Simply stated we imply that the latitude and longitude for station MEADES RANCH in Kansas will no longer be the origin of the North American Datum and the Clarke Ellipsoid of 1866 will be replaced by an ellipsoid more representative of the Earth on the whole. Plans have been made, in cooperation with the international geodetic community, for the adoption of a new reference system in 1979. Most of the effort in the United States is in converting the available observational data into computer-readable form. To date, we have keypunched the latitudes and longitudes and certain other information for about 250,000 points which make up the National Network of horizontal control. In addition, elevations from various sources, including those scaled from topographic maps, have been keypunched for all monumented stations. Descriptions for the stations have not been keypunched although various pilot projects have been contracted. We have placed in computer-readable form and evaluated through an adjustment process, observations associated with 45,000 stations. In addition, the entire astronomical data file has been placed in a computer-readable form.

A key ingredient in the tremendous job of performing this adjustment is in the development of a data base and a data base management system capable of supporting the tremendous data manipulation associated with this project. The first version of that data base is scheduled for completion this year. Consideration has been given to future applications of the users of NGS data, in addition to servicing the adjustment process. The data base features a simple query language, security provisions, and will contain about ten billion bytes of information.

The method of adjusting the data has been the topic of many discussions. We are planning to solve for the 500,000 unknown parameters (corrections to assumed latitudes and longitudes) partitioning the equations into blocks of approximately 1,000 stations.

Plans have been made to correct the observations for the deflections of the vertical and undulations of the geoid. These corrections will reduce the observations made on the physical earth, a slightly irregular sphere, to a mathematical figure, the reference ellipsoid. In order to accomplish this for all 250,000 points, we are planning to develop the corrections as analytic functions of position. Additional areas of research include the incorporation of the satellite results along with other extra-terrestrial data.

Each of the topics mentioned here will be covered in detail in subsequent articles. ■

Article No. 2

The Observables

by John G. Gergen

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NOS, NOAA, Rockville, Md.

The first article in this series authored by Capt. John D. Bossler appeared in the August 1974 issue of the *ACSM Bulletin*. The present article will address in detail the observables, i.e., the measurements which relate horizontal network stations such as horizontal directions, zenith distances, astronomic azimuths, and distance, as well as direct determinations of geodetic positions using satellite methods.

The observables have been obtained by employing a variety of instrumentation which will not be described here. However, in order to assure a high quality of the coordinates of horizontal network stations after the New Adjustment, it is of extreme importance to know the precision of the observations. Thus, we will describe the observables in terms of their standard errors. These standard errors always reflect the combined effect of internal and external errors which affect the observation.

The internal error is obtained from within the sample; its presence is readily apparent if one analyzes the sample, whereas the external error can only be obtained by comparing the mean values of several samples obtained under different conditions.

The internal error is basically instrument dependent, the external error depends on the instrument operator, weather conditions, observing techniques used, etc.

The actual values of standard errors given here are, at this time, preliminary; changes may result at the conclusion of continuing investigations.

Horizontal Directions

The vast majority of observables consist of horizontal directions. It is estimated that the horizontal network consists of ten horizontal directions for each theodolite occupied station, bringing the total number of horizontal direction observations to 2.5 million.

The precision of horizontal directions, in general, is given as a function of the order of the two end-points of the line.

The following table gives the standard error of a single observation and the average number of telescope positions for each order of station.

TABLE 1

The Precision of Direction Observations

Order of Point	Standard Error of a Single Observation	Average Number of Telescope Positions
High Precision	$2\overset{\prime\prime}{.}0$	32
First Order	2.4	16
Second Order	2.8	16
Third Order	3.4	8
Intersection	6.0	4

As an example, consider a line originating at a second-order station, to a first-order station: The lower station order will take precedence, and thus, assuming 16 positions of the telescope, the standard error of the mean of 16 direction observations will be $2.8 / \sqrt{16} = 0\overset{\prime\prime}{.}70$.

Zenith Distances (Vertical Angles)

As distances became easier to measure with EDM (electronic distance measuring) equipment, the need for good elevations for points increased, and the National Geodetic Survey made it a policy to measure zenith distances at all projects. The standard error of the mean for zenith distances is $\sigma_z = 5\overset{\prime\prime}{.}0 + 1\overset{\prime\prime}{.}0/\text{km}$.

Astronomic Azimuths

The standard error of astronomic azimuths is a function of the internal precision ($\sigma_a = 0\overset{\prime\prime}{.}5$), and the external precision. The determination of the external precision of astronomic azimuths is presently being investigated using Model II variance techniques, by the Gravity, Astronomy and Satellite Branch of the National Geodetic Survey. Conclusions drawn from this investigation will be presented in a later issue of the *Bulletin*.

Distance Observations

The standard error of distance observations is composed of two parts: an instrument constant standard error and a distance-dependent standard error.

Using the notation ppm for parts per million of the distance, the following table gives mean values of standard errors in the four broad categories of distance measurements:

TABLE 2

The Precision of Distance Observations

Type of Measurement	Standard Error	
	Constant	Distance Dependent
Short Distance Under 50 m	1 mm	
Taped Base Lines	10 mm	1.5 ppm
Lightwave EDM Instruments	15 mm	1.0 ppm
Microwave EDM Instruments	30 mm	3.0 ppm

The above values for EDM instruments are average values. They may change somewhat for specific instruments.

Position Observations

Present plans call for the observation of about 150 Doppler satellite positions in the conterminous United States and Alaska.

Preliminary investigations into the precision of Doppler point positioning have shown that the standard error of each coordinate (X, Y, Z rectangular earth-centered coordinates) is of the order of 1.0 m. ■

Article No. 3

Data Capture and Validation

by Gary M. Young

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The massive effort required to place the observational data associated with conventional geodetic surveys (horizontal directions, zenith distance (vertical angle) observations, taped and electronically measured distances, and astronomic positions and azimuths) in computer-readable form, and to perform a preliminary validation and analysis of the data through an adjustment process will be explained in this segment of the series. Doppler satellite positions, which will also be included in the New Adjustment, will be considered in detail in a subsequent article.

The processing and evaluation of the data, which began in earnest in July 1974, is being accomplished at the individual project level incorporating highly sophisticated computer software. The initial processing involves the conversion of the observational data in each of the approximately 5,000 projects currently in the NGS archives into computer-readable form. This is accomplished by analyzing the observational data and providing sufficient instructions to insure that the data is properly transferred to punched cards. In addition to the observed value itself, important associated information becomes a part of the observation record. These include a source document identification, the date of observation, a determination of station intervisibility at ground level, and a preliminary observational standard error based on the type of instrument and the number of repetitions.

Horizontal directions are placed in computer-readable form directly from abstracts of directions. The idea to obtain the data from lists of directions was abandoned because: (1) abstracts of directions represent the data as observed in the field (numerous observations rejected by field personnel, and not shown on lists of directions, are placed in computer-readable form utilizing abstracts of directions), and (2) lists of directions often combine distinct station occupations or reobservations, in which case orientation unknowns would not be assigned to each set of observations during the adjustment phase.

The data is then thoroughly checked, transferred to computer storage, and subjected to two adjustment runs. During the adjustment phase, certain corrections are computed and applied to the observations to reduce them to a common computational surface—the reference ellipsoid. Horizontal directions are corrected for: (1) the deflection of the vertical (where deflection values have been determined), (2) for the skew normal, and (3) for the geodesic. Distance observations are reduced to the ellipsoid by applying a correction which incorporates geoid height information. Astronomic azimuths are corrected for: (1) the deflection of the vertical, (2) the geodesic, and (3) the Laplace correction which converts an astronomic azimuth to a Laplace (geodetic) azimuth.

The first adjustment, a minimally constrained one, is performed to evaluate the "primary" horizontal directions in the project. Since exact relative observational standard errors are not known, the minimally constrained adjustment (which holds the position of one station fixed, and includes one distance and azimuth to provide scale and orientation for the project) avoids the contamination of the horizontal directions which could occur if erroneously weighted constraints were introduced. In this way, the residuals obtained for the horizontal directions provide a better statistical estimate of the accuracy of the horizontal directions than would be obtained if redundant distances or azimuths were added. The results will be utilized as part of a scheme to assign final weights to the horizontal directions.

The second adjustment, using the same fixed station, adds to the "primary" horizontal directions those considered to be "secondary" in nature, i.e., horizontal directions to supplemental and intersection stations, and all distance observations and astronomic azimuths present in the area of the project. The adjustments are then analyzed and preliminary recommendations for rejecting questionable observations and for observing additional horizontal directions, distance observations, or astronomic azimuths are made.

The next step in processing the data is to combine adjacent projects into larger blocks of work, possibly 2° x 2° in size, in which "between project" inconsistencies are eliminated and final recommendations for rejecting observations and for additional observations are made. The cleansed data is then stored in the NGS (National Geodetic Survey) Data Base awaiting the New Adjustment.

It is estimated that the 5,000 projects contain 2.25 million observations which will participate in the New Adjustment: 2,000,000 horizontal directions; 200,000 zenith distance observations; 20,000 measured distances involving 45,000 distinct observations; and 3,500 astronomic azimuths. Also being processed by NGS are approximately 3,500 astronomic positions needed to compute Laplace corrections for the astronomic azimuths, and the 600,000 horizontal directions and 400,000 short distance observations to the peripheral points (azimuth and reference marks) present at most positioned stations. An effort equivalent to about 200 man-years will be required to process and analyze the projects.

In addition to NGS projects, the projects include all acceptable work performed by other federal agencies, state and county agencies, and private groups, which is presently stored in the NGS archives and which contributes to the National Net.

The end product of this massive effort will be the first general readjustment since 1927. The New Adjustment, which is scheduled for completion in 1983, will provide improved positions for the more than 200,000 positioned points in the National Network of horizontal control. ■

Article No. 4

Data Base Management System

by David E. Alger

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As a result of the New Adjustment of the North American Horizontal Datum, the National Geodetic Survey (NGS) has embarked on a massive automation project which will place all observations, positions, and descriptions in the NGS archives into computer-readable form. The organizing, storing, and manipulating of the huge amount of data that is associated with 200,000 horizontal control stations presents several unique problems. This article will describe briefly the Data Base Management System (DBMS) which has been designed to handle and maintain this massive amount of data.

The NGS DBMS is designed to be general in nature and user*-oriented. It is modular in design; that is, each logically independent function is performed in a separate section of software. This enables new applications and data types to be added as needs arise. The DBMS is comprised of three major subsystems:

A. *Query Language Subsystem*

This allows users to enter, update, and retrieve data, using understandable, English-like requests rather than complex computer terminology. The language is definable by the major application areas in NGS (horizontal, vertical, etc.). The terms selected to perform certain functions or groups of functions (a process) can be added or deleted as necessary. This enables users to learn the method without being a computer expert. An example of a simple user request through the query language is shown below. The system assumes certain defaults (predefined values) if all details are not spelled out. This enables the user to specify a minimum request, or, if desired, to specify a more detailed one.

Example: *Simple Request*

```
GET HORIZONTAL POSITIONS, QUAD=0360861
```

Complex Request

```
GET HORIZONTAL POSITIONS, QUAD=0360861,
OUTPUT=TAPE, VOL=037192, FORMAT=GPCARD
```

B. *System Supervisor Subsystem*

The system supervisor is a collection of programs which control the processing of requests by the data base. It searches tables and determines which program to call for translating the user's request. It also determines defaults if information is not specified and locates space for input of data and work areas during processing. In addition, it performs periodic maintenance on files as well as making security backup copies of the data. Another unique feature is data migration, the moving of data from disk to tape and back, dependent on usage. The large amount of data makes it impossible to store it all on disk at any one time but, when using this data, it is most advantageous to have them on disk for quicker access. The system supervisor watches the data base user and automatically tracks the use of the data and moves static data back to tape after a period of inactivity (determined by the user groups).

C. *Application Subsystem*

The application subsystem is the most dynamic in the DBMS, since new applications are constantly being added. Currently, the major applications under development are in the area of the New Adjustment of the North American Horizontal Datum.

The first application for the adjustment was the storing and manipulating of the 200,000 station positions. This application was used as the foundation of the horizontal data; unique identifiers were assigned to each station, which will be used to match the other types of data (observations, descriptions) in the data base. This identifier is based on the station's position as well as a sequential assignment within a given area (7½' quads). During the automation, validation, and entry process of all data types, this identifier will be tagged to each record to enable retrieval in an organized general fashion.

The second major application was retrieval of data that is used for tagging other data types for entry (astronomical observations, horizontal observations, descriptions). This retrieval is now being done by an area of latitude and longitude, but will eventually allow retrieval by state, county, and special qualified areas (i.e., an area with just those stations of a specific type and order of accuracy).

In addition, applications are under development to organize and aid in the formation of blocks of data as needed to perform the New Adjustment and produce an automated data sheet for publication. These applications will greatly increase the cycle time of surveying, adjusting, and publishing data.

The DBMS is a tool which will enable NGS to perform its mission more efficiently and become more responsive to requests from the public. ■

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*User—is defined here as employees within NGS; scope of user will be expanded as need arises.

Article No. 5

The Network Adjustment

by Robert H. Hanson

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The previous four articles in this series discussed the work being done by the National Geodetic Survey (NGS) to select, automate, and preprocess data in preparation for the new adjustment of the North American Datum (NAD). This article outlines some of the principal techniques which are being used to perform the final task—a rigorous least-squares adjustment involving hundreds of thousands of observations and unknowns.

When dealing with the adjustment of small geodetic control networks, brute-force methods are extremely attractive. One simply forms, reduces, and solves a matrix containing a certain number of normal equations without regard to any savings in computer time or central memory storage that might be gained by the use of more sophisticated techniques. The relatively minor inefficiencies and small amounts of wasted time are largely offset by the ease and simplicity of computer programming. As networks grow larger, however, time and memory requirements grow exponentially and, unless steps are taken to avoid it, computing time rapidly becomes exorbitant and the central memory storage of even large-scale computers becomes inadequate. For a network such as that which covers the North American continent, the approximately 400,000 unknowns would require $400{,}000^2$ words of storage just for the normal equations alone if only brute-force methods were employed. There are a number of devices to cut the space and time requirements down to manageable limits. Four especially significant ones are discussed here.

The first is symmetry. Because the elements above the main diagonal of a normal equation matrix are identical in value to the corresponding elements below the diagonal, only the upper triangular part of the matrix need be formed, stored, and operated on. This cuts the storage requirements almost in half.

The second device has to do with sparseness. In a typical geodetic control network, an average station may be connected by way of direction or distance observations to something like eight or ten other stations. These connections appear in the normal equations matrix as nonzero terms at the intersections of the rows and columns containing coefficients of unknowns of connected stations. When the normal equations are reduced by the elimination of certain nuisance parameters, the number of such interstation connections may be increased as much as twofold. In no instance, however, is every station connected to every other station. The result of all this is that a typical normal equations matrix contains many more zero than nonzero elements. For networks of a few hundred stations, only five to ten percent of the elements are nonzero and the percentage tends to vary inversely with the size of the matrix.

Although originally very sparse, subsequent elimination-reduction operations create additional nonzero elements in the matrix. However, the total number of new nonzero, or fill-in, elements created depends on the order in which the unknowns are eliminated. By a suitable rearrangement of the unknowns, the number of fill-in elements can be drastically reduced, thereby cutting down on both storage requirements and computing time. An added benefit of reducing the number of computations is that the accumulated round-off error is also reduced.

A number of methods are available for automatically reordering normal equation unknowns to minimize fill-in, but the methods based on graph theory are most efficient. The graph theory algorithm selected for the NAD project was designed in-house by Dr. Richard Snay for maximum compatibility with the methods being used for matrix reduction.

A third device to cut storage requirements and thus make large adjustments possible is the use of peripheral storage hardware, such as random access disks. When a normal equation system is too large to be held entirely in central memory, even when symmetry and sparseness have been exploited, it can be partitioned and stored externally in a number of records. These records can then be moved into and out of central memory to accomplish the reduction and solution of the system.

Taking full advantage of symmetry, sparseness, and peripheral storage, today's large-scale computers would still not be able to handle super large networks, such as the NAD new adjustment, without a device referred to by geodesists as Helmert blocking. To apply this technique, a very large network is partitioned into a series of smaller subnetworks, or blocks, of one or two thousand stations each. We refer to these as being first-level blocks. Using all of the observations emanating from stations within a block boundary, a normal equation system is formed for each first-level block. Stations outside a block which have been observed from inside stations and stations inside a block which have been observed from outside stations are designated as junction-point stations. The distinguishing characteristic of junction-point stations is that observations which tie them to other stations are not all available at the time a first-level block normal equations matrix is formed. Consequently, contributions to their normal equation coefficients come from within two or more contiguous blocks. After forming normals for a block, all stations whose coefficients are fully formed are eliminated, leaving a reduced normal equation system containing partially formed coefficients of junction-point stations. At this stage the process is halted and the reduced normals output to external storage. The output from clusters of contiguous first-level blocks is then combined to form normal equations for a series of second-level blocks. Again, as with first-level blocks, fully formed coefficients are eliminated and the reduced normals from the second-level blocks output to external storage. The process is repeated through as many levels as necessary until the entire network has been processed. At the last level, a back substitution procedure is employed to solve for the last-level junction points. These solutions are then fed back into the partially reduced normals on the next lowest level and the solution process continued, each time passing solutions to lower levels until all of the solutions have been completed. The entire operation is then repeated, through as many iterations as necessary, until satisfactory convergence of the solution has been achieved.

These four devices—exploiting matrix symmetry, preserving and utilizing matrix sparseness, using peripheral storage devices, and employing Helmert blocking techniques—will enable us to perform the task of rigorously adjusting a network of several hundred thousand stations. Without them, such an adjustment would be virtually impossible. ■

Article No. 6

Doppler Satellite Positioning Program

by Larry D. Hothem

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In support of the new adjustment of the North American Horizontal Datum, Doppler satellite positions have been established or are planned throughout the North and Central American regions. The National Geodetic Survey (NGS) of the National Ocean Survey (NOS) has recently completed a primary network of about 150 Doppler stations in the conterminous United States. Approximately 100 additional stations are being established by NGS in Alaska, Hawaii, and Puerto Rico. Doppler stations are also being established in other areas of North and Central Americas by the national geodetic agencies of Canada, Denmark, and Mexico. These stations are spaced at intervals of 50-300 km, and will provide additional scale and orientation to the new adjustment.

The Doppler satellite positioning system is a method that employs worldwide geodetic positioning in a common geocentric (earth-centered) coordinate system. Johann Christian Doppler first stated the Doppler principle in 1842. As a source of wave motion approaches or moves away from the observer, the frequency of the waves either increases or decreases respectively. This phenomenon has been experienced by anyone who has heard a train whistle. The pitch changes as the train approaches the listener and then moves past.

Doppler signals from a satellite were first identified in 1957 by Drs. W. T. Guier and G. C. Wieffenbach, two scientists at the Applied Physics Laboratory of Johns Hopkins University. While monitoring Sputnik I, the first artificial satellite, they noticed the signals produced a characteristic Doppler curve at precise intervals. Later, they demonstrated that all orbital unknowns for a passing satellite could be determined by Doppler observations of a single pass from a single fixed station. Therefore, it was reasoned that if the satellite orbit were known, Doppler shift measurements could be used to compute one's position on earth. This concept led to the development of the Navy Navigational Satellite System (NNSS).

The NNSS now consists of six satellites in polar orbits reaching altitudes of 1000 to 1200 km with orbital periods of 105 to 110 minutes. At the equator these orbits are available for tracking every two hours; whereas, in the polar regions they can be tracked almost every 25 minutes.

For navigational purposes, the Doppler satellite observer uses the predicted orbital components broadcasted by each satellite. This broadcast message, which is updated approximately once every 12 hours, is used with the Doppler data to compute a position fix immediately upon completion of the observed pass.

To provide geodetic accuracies for single-station observations, the precise orbit of one or more NNSS satellites must be known. This post-orbital information is computed by the Defense Mapping Agency Topographic Center (DMATC) from data collected from about 22 worldwide fixed-tracking sites.

Originally, the equipment used for Doppler satellite geodesy was cumbersome, and a team of highly skilled technicians was required. Modern electronic advances and refinements have led to the miniaturization of Doppler satellite receiving equipment. Today's instruments are small, lightweight, and reliable, and require a minimum of logistical support (usually one to three persons). Power requirements are from 10 to 200 watts, depending on whether the data are recorded on paper or magnetic cassette tapes.

Doppler tracking receivers monitor the highly stable signals transmitted from the NNSS satellites and then compare these with the signals of the same frequency generated by the receiving equipment. The frequency of the signals received by the receiver appears to change as the satellite passes overhead. This change is caused by Doppler shift and is measured in terms of cycles over a given time interval. Later, these measurements are converted to ranges or distances to a satellite for a given time and, when combined with the precise orbital components, a geodetic position for the receiver antenna is determined.

As stated, there are two Doppler satellite ephemeris systems, predicted and precise. These systems differ primarily in terms of orbital accuracies. To achieve submeter accuracy with Doppler satellite positioning, the field observing procedures and data reduction methods must be carefully considered. The point-positioning method is used by NGS, where a single-station set of Doppler observations is reduced from precise orbital components. Since the precise ephemerides are produced by no more than two of the six NNSS Doppler satellites, the occupational period to track a minimum of 40 passes is about six working days.

Another approach to Doppler satellite positioning involves simultaneous observations of a common set of satellite passes from two or more stations. These data can be simultaneously reduced with the predicted ephemeris, and the results are equivalent to the precise ephemeris point-positioning solution in terms of relative position accuracy.

In addition to tracking the required number of satellite passes, the tracking team performs a survey tie between the receiver antenna and the horizontal and vertical geodetic networks. This tie permits the Doppler positions to be evaluated in comparison with an independent standard, or to be used for upgrading control network adjustments.

In the conterminous United States, approximately 50 stations of the 150 Doppler-station network are located on the high precision Transcontinental Traverse (TC). A recent NGS analysis of the comparison of Doppler satellite positions to TCT positions was made by B. K. Meade (retired), chief, Control Networks Division, NGS. His results showed that the estimated rms accuracies for the Doppler positions were 50 cm for latitude and 75 cm for longitude. A recent analysis by the author indicates that the estimated rms accuracy for height-above-ellipsoid is 50 cm. This conclusively supports the statement that Doppler positions would add considerable strength to the orientation and scale of the national horizontal network. With Doppler stations at about 300 km, the relative accuracy of azimuth and distance between stations is on the order of one part in 200,000 or better. For relative accuracy of about 1 part in 20,000, the spacing of the Doppler stations would be 30 to 40 km.

Investigations are underway by the NGS, as well as by other users of the Doppler satellite positioning technique, to determine whether improvements in the tracking equipment and field operating procedures, and refinements in the data-reduction programs, will improve the Doppler satellite-derived positional accuracies. Recent tests indicate that rms accuracies of better than 30 cm in each coordinate may be possible; a relative positional rms accuracy, particularly for latitude and height, may be possible within the 10 cm level.

The advantages of portability and accuracy of Doppler satellite positioning methods have led to their use for solving a number of different geodetic control requirements within NGS. In addition to providing scale and orientation for the new adjustment, the Doppler satellite coordinate system will be the basis for adoption of the new reference system in 1979. This earth-centered system will replace the Clarke Ellipsoid of 1866. Doppler satellite surveys are also being used to:

1. Update networks which have been distorted by past adjustment practices.
2. Establish geodetic control points at remote locations (e.g., islands, offshore structures) where conventional geodetic methods would be costly.
3. Place geodetic networks remote from each other on a common worldwide reference system.

Thus, the Doppler satellite positioning system has become an important tool, enabling the North American geodetic community to achieve its objective of performing a new adjustment of the North American Datum on an internationally adopted reference system. ■

Article No. 7

Geodetic Astronomy

by William E. Strange and James E. Pettey

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National Geodetic Survey
NOS, NOAA, Rockville, Md.

Geodetic astronomy will play an important part in the readjustment of the North American Datum (NAD). To support their readjustment, the National Geodetic Survey (NGS) will be using astronomic data for approximately 5,000 stations observed over a 130-year period. Astronomic azimuths (directions with respect to south) of surveyed lines will be used to provide essential orientation of the horizontal network on the Earth's surface. Astronomic latitude and longitude will be used for the following applications: necessary corrections to the astronomic azimuths in computing orientations; corrections to horizontal angle measurements used in triangulation; and, in conjunction with gravity data, the geometry of the sea level equipotential surface, the geoid. Also, astronomic latitude and longitude measurements will be used with several other types of geodetic data to establish the correct coordinate system to which the new NAD will be referenced.

With the observation of astronomic quantities over such a long period of time as 130 years, it is inevitable that changes and improvements involving instrumentation, observing programs, star catalogues, and time signals have taken place. This is particularly true of longitudes determined by this organization. Two methods have generally been employed by NGS in the determination of longitude: the telegraphic method, originated in 1846 by the U.S. Coast & Geodetic Survey (now the National Ocean Survey), was used exclusively until 1922. Beginning in 1922, the wireless (radio) method was adopted and is currently the method in use.

Significant improvements in instrumentation have included the chronographic time recorder, replacing the Audio (Ear) method of timekeeping; followed by the hand-driven tracking eyepiece, which replaced the manual key method; and finally today's digital time recorder, which replaced the chronographic time recorder.

The changes made by NGS in star catalogues have generally occurred as the improved catalogues became available. For example, latitude determinations now are made in conjunction with the Smithsonian Astrophysical Observatory Star Catalogue, which superseded the Boss General Catalogue, which in turn replaced the Boss Preliminary Catalogue, etc. Similarly, longitudes based on the Eichelberger Catalogue were followed by the Third Fundamental (*FK*3) Catalogue, which was superseded by the *FK*4 Catalogue.

Because the astronomic data have been taken over such a long time period, involving various changes and improvements, an important activity has been the determination of corrections necessary to make them into a homogeneous data set. These have included corrections to account for the differences between the coordinates assigned to stars in the past and present-day star positions as defined by the modern *FK*4 star catalogue. For longitudes, corrections were necessary to account for differences between the modern international time system provided by the Bureau International de l'Heure (BIH) in France and time systems used in the past. Finally, corrections have been provided to account for polar motion—the motion of the Earth's spin axis with respect to points on the Earth's surface. These corrections have been provided by the BIH and the International Latitude Service (ILS). The ILS, in operation since 1898, consists of five astronomical observatories located along the same parallel of latitude and observing the same stars. Two of the ILS observatories, located at Gaithersburg, Maryland, and Ukiah, California, are operated by the National Geodetic Survey.

Another important activity has been the establishment of correct accuracy estimates for the astronomic positions and azimuths so that they could be used to contribute properly to the network adjustment process. Experience has shown that the internal precision figures arising from computation of astronomic quantities are not a true measure of their accuracy. Development of correct accuracy estimates has involved statistical evaluation of repeat measurements and a careful attempt to identify error sources.

The most important application of astronomic data is the establishment of Laplace stations—stations where astronomic latitude, longitude, and azimuth have been determined—to orient the horizontal network during adjustment. To support this activity, all astronomic data have been computerized and are being merged with the horizontal data into a common data base. For highest accuracy corrections for deflections of the vertical, differences between astronomic and geodetic positions should be applied to all horizontal angle measurements. These corrections are particularly important when the two ends of a line are at substantially different elevations. In mountainous terrain, this correction may reach as much as one second of arc; however, it is generally much smaller (<0"5) for the conterminous United States. NGS is presently engaged in the determination of longitude for 115 stations where this correction is considered significant.

Table 1 gives the estimated accuracy, in terms of standard error, of Laplace stations determined by the NGS over the last 130 years.

As mentioned in an earlier article of this series,* the total error budget of observables involves both internal and external sources, i.e., the total being the vector sum of the two, as represented in the last column of Table 1.

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*"The Observables," John G. Gergen ACSM *Bulletin*, No. 55, Nov. 1975.

Finally, it should be noted that while the latitude and azimuth error budgets may be considered time invariant for the 130-year period, this is not true for longitudes. As a result, the tabulated longitude error budget is to be considered as a pooled (average) estimate over the 130-year period. A breakdown of longitude precision statements, representative of various observational epochs, is presently being prepared by the Gravity, Astronomy and Satellite Branch, NGS.

By differencing astronomic and geodetic positions at points in a geodetic network, one obtains (to a close approximation) the slope of the geoid relative to an ellipsoid to which the geodetic network is referenced. By integrating these slopes (or astrogeodetic deflections as they are commonly called), one obtains the heights of the geoid, i.e., mean sea level, above the reference ellipsoid. NGS has computed a number of astrogeodetic geoids in the past, the most recent in 1975. This recent geoid is presently being used in the reduction of geodetic triangulation and traverse data. Information on geoid heights can be obtained from gravity data and Doppler satellite-derived geocentric positions as well as from astrogeodetic data. The geoid for the final computations of the NAD readjustment will be computed by combining astrogeodetic data with these other sources of information on geoid heights.

Table 1. Estimated accuracy of Laplace stations.

Type of Determination	*Internal Precision*	*External Precision*	*Total Precision*
Latitude	±0.″18	±0.″26	±0.″32
Longitude	±0.″20	±0.″45	±0.″49
Azimuth	±0.″3	±1.″1	±1.″1

Article No. 8

Block Validation and Data Entry

by John F. Isner

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Many readers who have been following this series of articles since they first appeared in August 1975 have expressed an appreciation for the awesome complexity of the new adjustment. Such readers correctly perceive the new adjustment as a collection of interrelated tasks, each of which is vital to the success of the program.

Data capture and validation at the individual project or field survey level (Young, ACSM *Bulletin*, No. 52, Feb. 1976) comprise the first and most critical task, and the commitment of National Geodetic Survey (NGS) resources has been commensurate with its importance. About 200 man-years will be required to: (1) put 5,000 archival projects into computer-readable form and (2) subject each project to a complex procedure culminating in the adjustment by least squares and statistical analysis of all observations contained within the project.

From the computer specialist's point of view, this is a validation process: that is, one which insures the integrity of information as it passes from one medium (handwritten records) to another (computer-readable cards, disks, or tape).

At the end of the road, sometime before 1983, will come the network adjustment (Hanson, ACSM *Bulletin*, No. 55, Nov. 1976). The complete national network, constructed from its constituent parts (the individual projects), poses an adjustment problem in 400,000 unknowns.

Between the validation of individual projects and the actual network adjustment is a space of time in which three things must be accomplished: (1) a higher level validation at the inter-project level to insure a good fit and to spot voids left by missing data, (2) construction of the national network from its parts, and (3) the merging of all other data types which will influence adjustment results, including astronomic data (Strange and Pettey, ACSM *Bulletin*, No. 57, May 1977), Doppler data (Hothem, ACSM *Bulletin*, No. 56, Feb. 1977) and gravity data in the form of predicted deflections and geoid undulations at each horizontal control point. Item (1) is referred to as "block validation," for reasons which will become apparent, while items (2) and (3) constitute "data entry." This article examines the procedures that have been developed to carry out these two key activities.

Block Validation

Errors in data which manage to elude our validation "traps" may well cause the network adjustment to fail. We do not mean "failure" in the total sense, but rather in the localized sense of Helmert blocking (Hanson, *loc. cit.*). A numerical singularity at one of the "higher levels" necessitates the repetition of one or more computer runs. Not only are these runs expensive, but tracing the source of error is fairly difficult at this point.

Block validation takes aim at the errors left over after validation at the individual project level. Such errors include the omission of stations or observations, the duplication of observations, and errors in observations that become apparent only when points are observed in more than one project.

The procedure requires a set of "blocks" (regular areas such as rectangles) which completely cover the national network. The larger a block, the more data it includes and the greater its potential for containing errors. A block may be designated any time after all individual projects in the area are judged to be complete. The relevant projects are collected, automatically assembled by a computer program, and a Helmert block extracted from the combined network.

The Helmert block is then subjected to a free adjustment. The adjustment immediately reveals errors of the above-mentioned types in the block interior. Corrections are made to the individual projects. These are then revalidated at the project level, thus guaranteeing the integrity of the data at the project level. Block validation is repeated until the free adjustment discovers no new errors.

Data Entry

In his article (ACSM *Bulletin*, No. 54, Aug. 1976), Alger described the first "application" of the NGS data base. This was the storing of records identifying and giving the position of each of the 250,000 stations in the national network. It was during this process that the assignment of a unique identifier to each station was made.

Until recently, all applications of horizontal geodetic data have been local in nature (confined to a local area) and, therefore, required identifiers which were only locally unique. Global applications of the national network, such as the new adjustment, require stations to be uniquely identified. It is the job of data entry to identify uniquely the standpoint and forepoint of each observation, so that the observation may be stored in the NGS data base and later retrieved for global applications.

In order to insure the integrity of the data passing block validation, the Helmert blocks developed in that process move directly into data entry and are protected from change throughout the data entry process. The continuity in the two procedures claims two additional benefits: (1) the choice of large blocks for block validation is also favorable for data entry, where each computer run has a large fixed overhead, and (2) the choice of Helmert blocks guarantees that all observations are entered and that no observation is entered twice. To verify the second claim, consider the following statements. The collection of blocks developed by block validation completely covers the national network. Since these are Helmert blocks, an observation belongs to exactly one block (the block from which it originates). If data entry follows block validation directly, then the desired result is achieved.

Conclusion

The need for preserving the integrity of data throughout the new adjustment has been given highest consideration in the design of block validation and data entry procedures. It would be both uneconomical and dangerous if block validation could affect a data item in such a way as to invalidate that item at the individual project level. Similarly, the gains of block validation must not be diminished by "corrections" made at data entry. Each new process benefits from the progressive elimination of errors by the validation processes that precede it.

The care and attention invested now will have their final reward in a successful new adjustment of the North American Datum. ■

Article No. 9

Plane Coordinate Systems

by Joseph F. Dracup

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Perhaps the single most important end product of the new adjustment of the North American Datum to the surveyor, engineer, and other users of geodetic control is the plane coordinate system or systems adopted as the national grid. There is little doubt that plane coordinates will continue to be favored over geodetic (geographic) positions by most in the profession for some time. However, it is worth mentioning that the electronic computer has made the computation and adjustment of survey data on the ellipsoid a relatively simple matter for any size project. For surveys covering wide areas or those of a special nature, the use of geodetic coordinates may be best in the long run. In this regard, one should remember that there is no need to be concerned with zone or state boundaries when geographic positions are employed nor to apply the several corrections inherent to grid systems where the equivalent computational accuracy is required. Furthermore, the effort to convert geodetic coordinates to any plane system is less than to transfer from one grid to another. Admittedly, where computers are available, the time differential is almost infinitesimal, but there is the cost for preparing the additional programs required to make these conversions. This matter will not be pursued further, since the intent here is to discuss the adoption of a national grid for surveying and mapping purposes. The versatility of geographic positions will be left to a future article in this series.

When it became evident that the redefinition of the North American Datum was a reality, one of the major issues that arose early in the discussions was the type of plane coordinate system which would best serve the nation on the whole. There were two points of view. Those who advocated retaining the state plane coordinate systems (SPCS) and others who believed that a single system was ideally suited for the purpose. The single system proponents contended that the present SPCS were cumbersome, since several projections involving more than 125 zones were employed.

A study was instituted to decide whether a single system would meet the principal requirements better than the SPCS, the principal requirements being ease of understanding, computation, and implementation. Initially, it appeared that adoption of the Universal Transverse Mercator (UTM) system would be the best solution because the grid had been long established; it was being used to some extent and the basic formulae are identical in all situations. However, on further examination, it was found that the UTM 6° zone widths presented several problems that might impede its overall acceptance by the surveying profession. For example: To accommodate the wider zone width, it is necessary to apply a scale reduction of 1:2,500 on the central meridian while similar reductions on the SPCS rarely exceeded 1:10,000. In addition, the so-called second term or (t-T) corrections to convert observed angles to grid values are considerably larger and come into play sooner on the UTM; and, of course, the zone definitions seldom coincide with state or county boundaries. These problems were not viewed as being of a critical nature by a large number of users. However, many other surveyors and engineers, who wanted a simple system which could be adapted to variable terrain situations, considered the UTM unacceptable, primarily because of the rapidly changing scale factors.

The study then turned to the transverse Mercator projection with zones 2° in width. This grid met the primary conditions set for the adoption of a single system. By reducing the zone width, the scale reduction and the second term corrections could, in a general sense, be viewed as no worse than those found in the SPCS. The major disadvantage of the 2° transverse Mercator grid is that the zones, being defined by meridians, rarely fell along state and county boundaries which, with few exceptions, delineated the SPCS.

A review was then made which showed that while many states would require two or more zones, the 2° grid could accommodate those who wanted the zones to follow county lines. Furthermore, this could be done without causing any greater distortions than presently exist in the SPCS, although one or two of the larger counties would require two zones. At this point the study returned to a reexamination of the SPCS.

In reevaluating the SPCS, three major factors for retaining the system were evident. One, the SPCS had been accepted by legislative action in 35 states. Two, the grids had been in use for more than 40 years, and most surveyors and engineers were familiar with the procedures involved in using them. Three, except for academic and puristic considerations, the SPCS are fundamentally sound. With the availability of some type of electronic calculator or computer to everyone, the fact that the SPCS required a large number of zones and employs several projections was considered to be of little consequence. For these compelling reasons, it was decided to retain the SPCS.

The decision was expanded to publish UTM coordinates to satisfy those users who prefer that system. Both grids will be fully supported by the National Geodetic Survey for surveying and mapping purposes.

The policy to adopt the SPCS, with certain modifications, and UTM grids, on an equal basis after the completion of the new adjustment in 1983, was described in the notice published in the *Federal Register*, Vol. 42, No. 57, Thursday, March 24, 1977, pp. 15913-15914. This notice is given in its entirety below.

National Oceanic and Atmospheric
Administration

NATIONAL OCEAN AND GEODETIC
SURVEYS

Policy on Publication of Plane Coordinates

The National Ocean Survey, National Geodetic Survey, determined it is in the best interest of the surveying and mapping community that two plane coordinate systems be published and supported beginning in 1983 with the North American Datum redefinition. These two systems will be identified as the "State Plane Coordinate" (SPC) and the "Universal Transverse Mercator" (UTM) systems.

The UTM system will consist of the transverse Mercator projection as defined in Chapter 1 of the 1958 Department of Army Technical Manual-TM5-241-8, changing only the definition of the datum. The SPC will consist of the same projections and defining parameters as published in USC&GS Special Publication 235 (1974 revision) and legally adopted in 35 states, except for the following changes:

1. The grid will be marked on the ground using the 1983 NAD.

2. Distances from the origin will be expressed in meters and fractions thereof. One additional decimal place should be used for the metric expression of a value previously expressed in feet.

3. The arbitrary numeric constant, presently assigned to the origin, will be unchanged but will be considered as meters instead of feet, except for the following: If a state elects to have a different constant(s) assigned to the origin so that the 1983 NAD plane coordinates will appear significantly different from the 1927 NAD positions, when considering the overall system, then the National Geodetic Survey will consider changing the origin constant. If the state so elects, it must amend its legislation to accommodate this change.

4. Michigan's transverse Mercator system will be eliminated in favor of the legislatively approved Lambert system.

5. Projection equations will be programmed such that the maximum computing error of a coordinate will never exceed 0.1 mm when computing the coordinate of a point within the zone boundaries.

A supplementary publication of SPC constants will not be published until 1982 to allow sufficient time for state legislative action.

These state amendments will be based upon the desires and needs within the states, recommendations of the National Geodetic Survey, and among other things will consider the following items.

1. Refinements to eliminate:
   a. Negative *Y* coordinates for certain islands on the Maine east zone.
   b. Negative *X* coordinates for points on the Dry Tortugas on the Florida east zone.
   c. Negative *Y* coordinates for some offshore points on the Louisiana south zone.
   d. Zone boundary in the State of Washington passing through Grant County following latitude 47°30' rather than the county boundary.
   e. Negative *X* coordinates for some points on Mona Island and vicinity west of Puerto Rico.

2. Urbanization that requires either different parameters for existing zones or additional zones such that a metropolitan area would be located in a single zone. For example:
   a. New York City
   b. Chicago
   c. Cincinnati
   d. Washington, D.C.

3. A change in the arbitrary origin as discussed above. This can be accomplished in most cases by:
   a. Changing the *X* coordinate constant of 500,000 to 300,000 or 700,000 where the transverse Mercator is used, or change the *X* coordinate constant of 2,000,000 to 4,000,000 where the Lambert is used.
   b. Changing the *Y* coordinate constant of zero to 500,000 or 1,000,000.
   c. Changing both *X* and *Y*.

The National Geodetic Survey will not change projection defining parameters in states that have legally adopted the SPC system until the state amends its legislation.

Dated: March 18, 1977

T. P. Gleiter,
Assistant Administrator for Administration
(FR Doc. 77-8847 Filed 3-23-77; 8:45 am) ■

Article No. 10

Prediction of Roundoff Errors

by Peter Meissl

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The readjustment of the North American Horizontal Datum requires the solution of a system of about 500,000 simultaneous linear equations. In article no. 5 of this series, R. H. Hanson outlined special properties of this system and the adopted strategy for solving it. The most important property of the normal equation system is a large portion of zero coefficients. The system is sparse. The Helmert blocking adjustment technique makes efficient use of the sparse structure. It helps to organize Cholesky's algorithm in such a way that a great saving of computer storage and computation time is achieved. The system must be solved at least twice because we are dealing with a nonlinear network adjustment problem whose solution is obtained iteratively.

Roundoff errors arising and accumulating during the solution of the large system cause some concern. In the past roundoff errors have occasionally caused breakdowns in network adjustments. Although the network's size was never the only reason for such a failure, the question arose whether the readjustment of the North American network would be numerically safe if done in floating point with an equivalent of 14-16 decimal digits.

Any of the four elementary arithmetic operations, addition, subtraction, multiplication, and division, is susceptible to a roundoff error when executed by a computer. The result of an elementary operation obtained by the computer deviates from the mathematical result. This difference is called "elementary roundoff error." Elementary roundoff errors depend on the design of the computer's arithmetic unit. Two computer families, one represented by the CDC 6600 and the other by the IBM 360, were considered.* The CDC 6600 uses the binary number system. Floating point numbers have mantissas of 48 bits which are equivalent to about 14 decimal digits. The CDC 6600 performs nearly true rounding if special care is taken by the programmer. True rounding means upward or downward such that the roundoff error is minimized. The IBM 360 utilizes the hexadecimal system. The base of the number system is 16 and not 2 (as in the case of the CDC 6600) or 10 (as in the commonly used decimal system). The IBM 360 may be programmed such that floating point numbers comprise 14 hexadecimal digits. This is equivalent to about 16 decimal digits. The IBM 360 does not round truly and does not even come near to it. It "chops" or "truncates," which means that it always rounds downward. Actually, we should not use the word "always" since there are a few exceptional cases where the IBM 360 rounds upward. Chopping causes a larger roundoff error, but this is not the main disadvantage. The real danger of chopping comes from the bias that it introduces. The rounded results are not statistically scattered in a way such that the true result is at the center.

It is estimated that about 2 x 10^{11} elementary operations are performed during the solution of the normal equation system. This number may be off by a factor of 2 or 3. Roundoff error investigations are, after all, concerned with orders of magnitude rather than with specific numbers. Any elementary roundoff error has an effect on the final results—the coordinate shifts of some 200,000 stations. A linear and statistical roundoff error model has been adopted. Linearity allows us to consider the isolated effect of one particular elementary roundoff error onto the result and to superimpose the individual effects afterwards. The statistical feature of our model amounts to viewing the elementary roundoff errors as random phenomena. We treat the elementary roundoff errors as statistically independent random variables, allowing us to apply the same mathematical tools to their analysis as for observation errors.

The perturbance of the solution due to a single elementary roundoff error resembles the response of a linear system to an impulse-type disturbance. J. H. Wilkinson has pointed out that the mathematical analysis is appreciably simplified if the elementary roundoff errors are traced backward to the original system, rather than propagated forward through the subsequent computational steps. Wilkinson's so-called "backward analysis" results in a perturbance of the original system whose effect on the final solution may be estimated in an elegant and systematic way.

To judge the effect of a single elementary roundoff error, one must be concerned with two items: (1) its size, and (2) the shape and amplitude of the response function which perturbs the coordinate shifts. The size of the elementary roundoff error depends on the size of the operands. Exceptionally large coefficients of the normal equations pose a threat if the effect of the large elementary roundoff errors which they cause is not counteracted by a small amplitude of the response function. An unfortunate situation, where such an offsetting does not occur, results from so-called weight singularities. A com-

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Mr. Meissl is chairman, Institute for Mathematical and Numerical Geodesy, University of Graz, Austria. This research was conducted while the author was a National Research Council, National Academy of Sciences, senior scientist in geodesy.

*Technical considerations are cited as they apply to this research. No product endorsement by the U.S. Government is intended or should be inferred.

paratively small number of observations are of much higher accuracy than the others. Such observations usually provide strong ties between narrowly clustered stations. If the spacing between two stations is only a few meters, it is likely that the distance between them is taped with millimeter accuracy. This compares unfavorably, in the numerical sense, to the accuracy of observations between stations at "normal" distances of 10-40 km. It turns out that the weight singularities are actually the limiting factor to the numerical accuracy of the solution of the readjustment's normal equation system. The size of the network is not so critical. Weight singularities could be removed prior to the formation of the normal equation system by certain transformations. However, this is undesirable since it makes the computational process and the manual preparation of the data much more complicated.

The analysis of the response function relies on special properties of the network. The investigation of the interaction of these properties with roundoff error propagation accounted for most of the time spent on the roundoff study. In this short exposition it can only be mentioned that the transcontinental traverses and the Doppler stations have a very favorable effect on keeping down the amplitudes of the response function. Helmert blocking keeps the number of elementary roundoff errors relatively small. Hence we were able, after all, to predict numerical feasibility of the adjustment on both families of computers.

It can be guaranteed that by using the CDC 6600 and the IBM 360 at least 2-3 leading decimal digits of the largest coordinate shift will be recovered correctly during one iteration. With a small probability of error it can be predicted that about two more decimal digits will be correct. Relative positions of closely situated stations, i.e., the differences between their latitudes and between their longitudes, will be even more accurate—on the CDC 6600 by at least a power of 10, on the IBM 360 perhaps even by two powers of 10. Although the IBM 360 has the equivalent of about two more decimal digits than the CDC 6600, in our present problem this is offset by the less favorable rounding properties. ■

Article No. 11

Automated Publication of Horizontal Control Data

by Lieutenant Commander Ludvik Pfeifer

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Past articles in this series have dealt with the concept of the New Adjustment of the North American Datum to be completed in 1983 and with several of the preparatory phases, such as the digitizing and preprocessing of archival observations. In this article, the elements of automated publication of horizontal control data—the station synopses and station descriptions—are traced through the digitizing process, and a new computer-generated Horizontal Control Data Sheet is unveiled.

The first major task which had to be undertaken as a part of the New Adjustment process was the digitizing (conversion to computer-readable form) of parametric data pertaining to each horizontal control point, of which there are some 200,000 in the publication annals of the National Geodetic Information Center (NGIC). This task involved the compilation and keying of such data as the station name, position, elevation, state in which located, applicable state plane coordinate zones, azimuth reference data, and other necessary information comprising a "synopsis" of each horizontal control point.

The Horizontal Synoptic File, as it is called, consists of 80-character card images, normally three per horizontal control point or four if an alternate azimuth reference object is specified, totaling approximately 50 megabytes of station-specific data. This file, in its entirety, has now been entered into the National Geodetic Survey Data Base, where each synopsis serves as the nucleus of the respective station record. Aside from the synopsis, each station record will eventually contain the field observations (directions, distances, vertical angles), astronomic and satellite observations, if any, and the respective station description and all subsequent recovery notes.

Compared to the synopses, the conversion of descriptive data to computer-readable form is a task of much larger magnitude. It involves the screening, editing, annotation, and keying of a station description plus a variable number of recovery notes for each horizontal control point. Although the amount of descriptive data varies widely from station to station, on the average some forty 80-character card images are required per horizontal control point, leading to a total of approximately 650 megabytes of horizontal descriptive data to be processed. After three years of steady effort, about 70 percent of this descriptive data volume is in computer-readable form at the present time.

By the time this article goes to print, the National Geodetic Survey Data Base is expected to have the capability of accepting horizontal descriptive data. At the time of data entry, each station description and/or recovery note will be matched with and linked to the corresponding synopsis which already resides in the Data Base. After the entry of descriptive data for a significant number of horizontal control points, the Data Base will become capable of supporting the first major application—the automated retrieval and publication of horizontal control data.

The basic vehicle for the automated publication of horizontal control data is a computer-generated data sheet, an example of which is given in Figure 1. This new Horizontal Control Data Sheet has been designed for composition on state-of-the-art peripheral equipment—the line printer for immediate availability of hard copy, off-line Xerox printer for small-scale publication purposes, and CRT microfilm for large-scale publication via conventional printing process. It consists of two distinct parts—the synoptic section which appears at the head of the page, followed by the descriptive section which may spill over onto the next page and may take up several consecutive pages in the case of a horizontal control point with many recovery notes.

Although the data elements are arranged in a different manner, the user of geodetic data will have no difficulty in recognizing the data items in the synoptic section which he is used to seeing on a Horizontal Control Data Sheet. There are, however, some important additions: (1) the Universal Transverse Mercator (UTM) coordinates are given for the zone into which the control point falls and for the next adjacent zone to whose boundary the control point is nearer, (2) the elevation (above geoid) and its source as well as the geoid height (vertical distance from the reference ellipsoid to the geoid) now appear as standard data items, (3) the State Plane Coordinates (SPC) are given in both American survey feet and in meters (1 survey foot = 1200/3937 meters exactly), and (4) a cautionary note alerts the user to the fact that the arch-to-chord (t-T) correction has not been applied to the UTM and SPC grid azimuths given.

In the descriptive section, the format of the station description and of the recovery notes is essentially the same as that used in the past. A few notable innovations are as follows: (1) the mode of transportation used to reach the station and the pack time now appear as explicit data items in the heading, (2) the Standard Numbered Notes of USC&GS Special Publication 247 have been replaced by a more comprehensive set of codes with provision for the magnetic property of the mark, and (3) in the reference data section, provision is made for the labeling of the distances measured to peripheral reference and/or azimuth marks as "horizontal" or "slope."

The National Geodetic Survey plans to take advantage of this long-awaited capability and start to publish horizontal control data in the new format as soon as the entire process becomes operational later this year. The data will continue to be packaged in the familiar 30 x 30-minute "quad" volumes; however capability will exist to combine several adjacent quads into a single volume in areas of sparse control, as well as to publish 15 x 15-minute and even 7½ x 7½-minute subquads as separate volumes in areas of dense control.

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                                           ***PRELIMINARY***                                    PAGE--022
US DEPARTMENT OF COMMERCE - NOAA          HORIZONTAL CONTROL DATA               QUAD--N38082243 QSN--0001
NOS - NATIONAL GEODETIC SURVEY           NORTH AMERICAN DATUM 1927              STATE--WV  DIAGRAM--NJ 17-4
ROCKVILLE MD 20852 - OCT 1977          ADJUSTED BY--CGS     YEAR--1958          COUNTY--WAYNE
                                              SOURCE--G11678

STATION NAME--NEWCOME                                                 PRIMARY       GEODETIC AZIMUTH (FM SOUTH)
     TYPE--2ND-ORDER TRIANGULATION                                    AZIMUTH REFERENCE OBJECT--    (DEG MIN SEC)
   EST BY--CGS    YEAR--1957                                          NEWCOME AZ MK                   24 34 54.0

                                            UNIVERSAL TRANSVERSE MERCATOR    POINT    CONVERGENCE    GRID AZ TO
     GEODETIC POSITION                           COORDINATES IN METERS        SCALE    OF MERIDIAN  AZ REF OBJECT
      (DEG MIN SEC)                         ZONE  X-EASTING  Y-NORTHING      FACTOR   (DEG MIN SEC) (DEG MIN SEC)
   LAT  38 18 31.23770N                      17  369099.847 4240918.191   0.99981102   -0 55 41.5   205 30 35.5*
   LON  82 29 49.75970W                      16  893779.358 4249460.968   1.00151017   +2 47 41.6   201 47 12.3*

   ELEVATION (MTRS)  297.1   SOURCE OF ELEVATION DATA--TRIGONOMETRIC LEVELING   MODELED GEOID HEIGHT (MTRS)  -2.5

                          STATE PLANE COORDINATES IN SURVEY FEET AND METERS   PT SCALE   CONVERGENCE    GRID AZ TO
        STATE-ZONE CODE    X (FEET)    Y (FEET)     X (MTRS)    Y (MTRS)       FACTOR    OF MERIDIAN  AZ REF OBJECT
           WV-S    4702   1570427.60   479995.27   478667.291  146302.850   0.99992802   -0 55 31.9     25 30 25.9*
           KY-N    1601   2502946.72   299268.69   762899.686   91217.279   0.99996589   +1 05 25.3     23 29 28.6*

                                                                          *CAUTION - ARC-TO-CHORD CORRECTION ASSUMED ZERO

                    *****************  S T A T I O N   D E S C R I P T I O N  *****************
STATION NAME--NEWCOME                                  STATE--WV  COUNTY--WAYNE                 QUAD--N38082243 QSN--0001
********************************** YEAR COP ***************************** REACHED BY ****** PACK TIME ** HGT OF TELESCOPE
MONUMENT BY--CGS                   1957 FAR   MKR TYPE--TRIANG STA DISK   TRUCK              00 HRS 00 MIN       15 METERS

             CODE MARK TYPE ********* SETTING/LANDMARK TYPE *************************************** MAGNETIC PROPERTY
      SURFACE--D09  SURVEY DISK         SET INTO THE TOP OF A SQUARE CONCRETE MONUMENT                UNKNOWN
  UNDERGROUND--D04  SURVEY DISK         SET INTO THE TOP OF AN IRREGULAR MASS OF CONCRETE             UNKNOWN

                 REFERENCE OBJECT ********** HEADING/DISTANCE (MEASURED OR ESTIMATED) ** DIRECTION
                 DAVIS 2                                                                  0 00 00.0
             D09 NEWCOME AZ MK                 SSW   ESTIM APPROX 0.4 MI                135 03 51.3
             D09 NEWCOME RM 2                  WNW          42.89 FEET  13.073 MTRS     214 01 55
             D09 NEWCOME RM 1                  ENE          66.12 FEET  20.153 MTRS     358 50 15

STATION IS APPROXIMATELY 6.5 MILES NORTHWEST OF WAYNE, 3.0 MILES WEST OF LAVALETTE, NEAR THE HEAD OF NEWCOME BRANCH AND
ON THE HIGHEST POINT OF A HILL OWNED BY MRS. MARTHA WORKMAN.

TO REACH FROM THE JUNCTION OF U.S. HIGHWAY 60 AND U.S. HIGHWAY 52 IN HUNTINGTON, GO SOUTH ON U.S. HIGHWAY 52 FOR 6.3
MILES TO THE JUNCTION OF STATE HIGHWAY 75, KEEP LEFT ON U.S. HIGHWAY 52 FOR 0.85 MILE TO A SIDE ROAD ON THE RIGHT AND
SIGN LAVALETTE NURSERY 100 YARDS, TURN RIGHT, CROSS STEEL BRIDGE, KEEP LEFT AND FOLLOW THE MAIN TRAVELED ROAD FOR 2.85
MILES TO A SIDE ROAD ON THE RIGHT, KEEP LEFT, PASSING SCHOOL AND CHURCH ON THE LEFT AND GO 0.25 MILE TO A SIDE ROAD ON
THE RIGHT AND A HOUSE ON THE RIGHT, TURN RIGHT, CROSS STREAM AND FOLLOW ROAD ALONG STREAM FOR 1.5 MILES TO TOP OF HILL
AND A DIM ROAD ON THE LEFT, KEEP RIGHT AND FOLLOW ROAD ALONG RIDGE FOR 0.1 MILE TO THE AZIMUTH MARK ON THE LEFT.
CONTINUE ON ROAD FOR 0.3 MILE TO A ROAD ON THE LEFT LEADING TO MRS. WORKMAN'S HOUSE, TURN LEFT AND GO 0.2 MILE TO MRS.
WORKMAN'S HOUSE, PASS TO THE NORTH OF HOUSE ON FIELD ROAD AND GO EASTERLY ON RIDGE FOR 0.15 MILE TO THE HIGHEST POINT OF
HILL AND THE STATION.

STATION MARKS ARE STANDARD DISKS STAMPED---NEWCOME 1957---.  THE SURFACE DISK IS SET IN A SQUARE CONCRETE POST WHICH
PROJECTS 4 INCHES.  IT IS 12 FEET NORTH OF A PINE TREE WITH A TRIANGLE BLAZE ON THE NORTH SIDE.  THE UNDERGROUND DISK IS
SET IN AN IRREGULAR MASS OF CONCRETE 24 INCHES BELOW THE SURFACE OF THE GROUND.

REFERENCE MARK NO. 1, A STANDARD DISK STAMPED---NEWCOME NO 1 1957---, IS SET IN A SQUARE CONCRETE POST WHICH PROJECTS 4
INCHES.  IT IS 7 FEET SOUTH-SOUTHWEST OF A PINE TREE WITH A TRIANGLE BLAZE ON THE SOUTH SIDE, APPROXIMATELY 7 FEET
LOWER IN ELEVATION THAN THE STATION AND ON THE NORTHEAST SLOPE OF THE HILL.

REFERENCE MARK NO. 2, A STANDARD DISK STAMPED---NEWCOME NO 2 1957---, IS SET IN A SQUARE CONCRETE POST WHICH PROJECTS 4
INCHES.  IT IS 4 FEET EAST-NORTHEAST OF A PINE TREE WITH A TRIANGLE BLAZE ON THE EAST SIDE, APPROXIMATELY 6 FEET LOWER
IN ELEVATION THAN THE STATION AND ON THE WEST SLOPE OF THE HILL.

AZIMUTH MARK, A STANDARD DISK STAMPED---NEWCOME 1957---, IS SET IN A SQUARE CONCRETE POST WHICH PROJECTS 4 INCHES.  IT
IS 175 FEET SOUTHWEST OF A GAS LINE CROSSING, 125 FEET NORTHEAST OF THE NORTHEAST CORNER OF MR. OTIS CRABTREES HOUSE, 13
FEET NORTHWEST OF THE CENTER OF A DIRT ROAD AND 1 FOOT NORTHWEST OF A FENCE LINE.

HEIGHT OF LIGHT ABOVE STATION MARK 18 METERS.

                    ***********************  R E C O V E R Y   N O T E  ***********************
STATION NAME--NEWCOME                                  STATE--WV  COUNTY--WAYNE                 QUAD--N38082243 QSN--0001
********************************** YEAR COP ***************************** REACHED BY ****** PACK TIME ** HGT OF TELESCOPE
RECOVERY BY--CGS                   1961 JJC  CONDITION--GOOD              LIGHT TRUCK        00 HRS 00 MIN          METERS

             CODE MARK TYPE ********* SETTING/LANDMARK TYPE *************************************** MAGNETIC PROPERTY
      SURFACE--D09  SURVEY DISK         SET INTO THE TOP OF A SQUARE CONCRETE MONUMENT                UNKNOWN

THE STATION AND REFERENCE MARKS WERE RECOVERED AS DESCRIBED AND FOUND TO BE IN GOOD CONDITION.
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Figure 1.

Article No. 12

Positional Data—Storage, Retrieval, and Maintenance

by John D. Love and James Drosdak

National Geodetic Information Center
National Geodetic Survey
NOS, NOAA, Rockville, Md.

The first geodetic data to be stored in the National Geodetic Survey's (NGS) data base in support of the New Adjustment of the North American Datum were positional data for horizontal control points of the national network. These data were loaded first to establish a reference system to which all other data elements can be correlated, thus enabling them to be entered, retrieved, and maintained within the data base. The other data elements include all observational data, astronomic results, station descriptions, and recovery notes.

In 1973, in support of semi-automating the publication of horizontal control by 30-minute quads, the NAD 1927 positional data and closely related associated information were keyed into machine-readable form. These data consisted of the results from projects adjusted up to that time by NGS. During the latter part of 1973 and the early part of 1974, approximately 250,000 horizontal control stations located in the conterminous United States, Alaska, Hawaii, and Puerto Rico were keypunched and stored on magnetic tape. Therefore, when the geodetic data base management system (DBMS) was ready for the first large-scale data entry in 1975, the adjusted NAD 1927 positions were available in machine-readable form.

Loading these data into the data base began in November 1976. By mid-1978, the loading of data for the conterminous United States and Alaska was completed. In addition, similar positional data from newly adjusted projects are being loaded into the data base as they become available for publication.

The steps leading up to and including the actual loading of these data in the data base logically fall into three distinct phases: digitization, pre-entry, and loading.

The basic data for each control station were digitized onto three computer punch cards. These data included the following: several identifying numbers or codes, station name, geographic position, elevation, state plane coordinate zone code, survey order and type of station, azimuth mark name(s), geodetic azimuth(s), and year of station establishment.

Digitizing these data was a fairly straightforward task; nevertheless, it was a formidable undertaking because of the large volume of data processed and the various "standard" formats of source material. Elevations had to be scaled from 7½-minute topographic map sheets for points without vertical control. Approximately 300 boxes of Hollerinth coded cards were punched from the source material; the review and research of this source material demanded considerable geodetic expertise.

The pre-entry phase in the processing of the horizontal control positional data began in November 1976 and continued throughout 1977. The source data for this initial entry into the data base were the 250,000 horizontal control positions and related data which were stored on magnetic tapes.

The data on the tapes were divided into data sets of approximately 3,000 horizontal control stations. These data sets were written on a direct access device. Each data set was then processed through a pre-entry process of two edit programs to ensure data integrity.

When the edit routine flagged errors, they had to be resolved through a lengthy research of the original source documents, archives, and, if necessary, the observation files. Each error was then corrected in the original data set through a remote terminal, utilizing the text editing program WYLBUR. A data set which successfully ran through the two pre-entry programs was considered validated and ready to be processed through the data base entry phase.

In the entry process, the data were purged for duplications, reorganized into 7½-minute quads, and stored on a dual-density direct-access device. A 0.3 second of arch comparison criterion was applied to identify duplicated stations.

The data were loaded completely under DBMS control, and the data base index and directory were automatically revised to show the location of the data within the data base. During loading, a unique identifier was assigned to each station. The station's unique identifier is the QIDQSN, Quad Identifier (QID) and a Quad Station Number (QSN). All future actions to that station are then made using this number.

When the DBMS becomes completely operational, the most obvious change in the publication of positional data will be in format. The most beneficial change should be the timeliness with which newly established horizontal control is published and existing control is revised.

After a horizontal control project is adjusted, the computed results are processed through the edit programs. New stations can then be immediately loaded into the data base. A similar procedure is followed to revise positional data that already resides in the data base.

All stored information concerning a revised station is moved to the automated history file which resides off-line. The history file provides a chronological record of a station and must be maintained in order for NGS to respond to inquiries concerning legal issues.

Ideally, updating the positional data immediately upon completion of final adjustment in a real-time environment is desirable but may not be practical. The data migration design of the DBMS will allow real-time operation. But even though the data will meet the criteria of the edit programs, human intervention probably always will be desirable for final control of quality and completeness before publication. Also, it will be more economical to update by defined geographic areas on a scheduled basis. The frequency of when an area should be updated depends on the activity within the area.

The query language for data retrieval has not yet been implemented for production use. Presently, retrievals against the data base are made by geographic areas defined by latitude and longitude in increments of the 7½-minute quad boundaries. This retrieval system satisfies most immediate requirements. Interim service will continue and will be improved upon while the DBMS continues development and implementation.

The majority of requests for automated data have been for data stored on a magnetic tape medium. Most users accept the data in the input card image form and reformat to their own specifications. A large group of requesters is composed of petroleum companies which require a geographic framework on which to build data bases of natural resource inventories. Requests for this type of application are anticipated to increase. New formats of the data may become necessary as more requests are received by the National Geodetic Information Center (NGIC), including microform or hard copy listings of selected data. Computer readable state plane coordinates generated from the data base positions have been furnished upon request. Land surveyors may desire these products once they are aware of the NGS computer-generated items.

The present horizontal control data sheets published by NGS will be replaced eventually by a computer-derived data sheet. This will be accomplished gradually as the descriptions are digitized and loaded in the data base. ■

Article No. 13

A Test of the New Adjustment System

by Edward L. Timmerman
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Previous articles in this series have reported on a variety of interrelated tasks, each an essential component of a highly complex computerized system which the National Geodetic Survey (NGS) has developed for the New Adjustment of the North American Datum. Readers who have been following this series of articles have seen that the New Adjustment system is centered around the NGS data base. Success of the future 1983 network adjustment will depend on the integrity of the massive amount of geodetic data gathered, sorted, validated, and entered into the data base.

With this in mind, NGS organized a four-member task force to test rigorously the complex computer software and data handling procedures developed for the New Adjustment. All plans formulated for completion of the tasks by 1983 were reviewed and revised.

The Test Area

The test area selected was a 3° by 5° block bounded in latitude by 35° and 38° in longitude by 83° and 88°—encompassing the States of Tennessee and Kentucky. This area was selected for two reasons: (1) The geodetic network in this block is representative of the entire national network, which is a mixture of arcs and areas of triangulation and traverse projects: (2) all projects in the region had been placed in machine-readable form (Young, *ACSM Bulletin*, No. 52, Feb. 1976). (See Table 1.)

Table 1: Test area statistics

Data	*Number*
Horizontal Projects	85
Horizontal Control Points	3,380
Horizontal Directions	19,399
Astronomic Azimuths	21
Distance Observations	1,935

Block Validation and Data Entry

In his article John Isner (*ACSM Bulletin*, No. 58, August 1977), said two key tasks needed to be accomplished before the actual network adjustment: (1) to combine the observational data in the individual projects to form a set of blocks to cover the national network completely. At the time these blocks are formed, a higher level of validation is performed to detect interproject problems (errors and omissions) and ensure a good fit. This process is called *block validation*; and (2) the cleansed blocks must be merged with all other data types in the NGS data base including astronomic, Doppler, and gravity data in such a way that the national network can ultimately be constructed from these constituent blocks. This constitutes *data entry*.

To do this, the test area was divided into four 1½° by 2½° blocks, one for each task force member. Working independently, each followed these steps: (1) Projects relevant to the assigned block were identified and gathered from NGS archival computer tapes; (2) each project was screened, by computer software, to ensure that data complied with current NGS standards and guidelines; (3) projects were combined to form a block and within block points were compared to publication data in the data base to confirm that none were missing; and (4) a minimum constraint least-squares adjustment was performed to determine project behavior in combination. This cycle process, execution of the four steps in succession with no new errors, ensured that corrections could never invalidate previous work.

Since horizontal directions could not yet be entered into the data base, the task force simulated the entry of the four blocks, and then simulated the merger of the horizontal observations with other types of observations, ensuring that the blocks consistently "connected." Both processes are considered cornerstones of data entry.

Finally the task force tested the critical software of the New Adjustment system—*the block adjustment program.*

Helmert Block Adjustment

The four test blocks were simultaneously adjusted in two levels using the Helmert block method. (See Table 2.)

Table 2: Test area adjustment results

Number of initial level (interior) stations	2,770
Number of junction points (higher level)	610
Degrees of freedom	8,893
Variance of unit weight	1.858

The large variance of unit weight is attributed to poor weighting. Software to recompute *a priori* standard errors using Ferrero's formula will be incorporated into the New Adjustment system but was not ready for this pilot test.

Conclusions

The Tennessee/Kentucky pilot test has yielded a wealth of information. Besides providing a valid test of the elaborate computer software, it isolated areas needing improved data handling procedures. But most important was confirmation that NGS is progressing on schedule towards its ultimate goal —the redefinition of the North American geodetic networks.

[*ACSM Bulletin*, no. 63, Nov. 1978, p. 15]

Article No. 14

Digitization of Station Descriptions

by William W. Wallace

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Automation of the descriptive data associated with horizontal control stations is required to support the New Adjustment of the North American Datum and meet the needs of the automated publication system of NOAA/NOS National Geodetic Information Center (NGIC). The progress and status of the conversion of descriptive data to computer-readable form is discussed here.

In January 1974, a 6-month pilot project commenced as part of a feasibility study for automating descriptive data. The pilot project employed a NOAA contractor and had four major goals: (1) evaluation of the accuracy of keyed data, (2) attainment of real cost estimates, (3) establishment of reliable turn-around times, i.e., time to prepare data for coding/keying in-house versus time for return of automated data from the contractor, and (4) determination of any format changes prior to finalizing the technical specifications for keying and coding data.

The pilot project clearly indicated that the descriptions could be effectively keyed under contract with an error rate of 0.3 percent or less. An alternative would have been to key the data in-house. But the volume of data to be converted and the number of people required to perform this task within the next several years made this alternative impractical. An estimated ten million 80-character records are contained in the horizontal descriptive files. This would have required ten people keying data for 5 years, and these figures do not include time for data preparation, coding, and post-automation validation and editing. As a result of this study, NGS has held contracts with several vendors outside of NOAA since 1974, and to date (1978) 125,000 horizontal station descriptions, including associated recovery notes, have been automated. The remaining 100,000 descriptions in the horizontal files will be converted to computer-readable form over the next 2 to 3 years.

The first step in the process leading to digitization of station descriptions is conversion of the data to 30-minute quads. Under the old publication process, stations were published by projects and usually distributed by county or state areas. The positional information associated with each station was digitized and placed in quad format during 1973 and 1974 (Drosdak and Love, *ACSM Bulletin*, No. 62, Aug. 1978). This enabled a computerized data sheet to be generated which contained automated positional-related data on the right hand side of the listing. Using a manual matching process, the descriptive information associated with the positional data for each station is attached to the left side of the data sheet. The descriptive data are keyed using these data sheets as source documents. A unique identifier previously assigned to each station's positional data is also keyed with the description. This identifier is used to match the automated descriptive data with the appropriate positional data within the NGS data base and thus provides the basis for an automated publication system.

After conversion to quads, the source documents are given to the contractor for coding and keying. The coding process involves extracting data from the source documents and placing the extracted data in the required format for the new publication. This operation is more complex than keying and usually is performed by more experienced personnel. After coding the data, keying is a relatively straightforward task. All data are key-verified by a person who did not perform the original keying. The key-verification process should ensure that the data are 99.7 percent error-free, as required. Most contractors use key-to-disk equipment for this operation and produce a final magnetic tape only when all reformatting and validation have been completed. Each tape sent to NGIC by the contractor contains approximately 10,000 to 12,000 records. To date, we have received and accepted 586 tapes containing horizontal descriptions from various contractors.

When the tape is received at NGS, it is run through an edit program to detect errors. The program is designed to catch those errors which involve incorrect formats, erroneous or misplaced data fields, voids in the data, and other non-textual type errors. The text of the description cannot be edited effectively by computer software. To evaluate the "cleanness" of the textual data, a random portion (usually 5 percent) of the text is proofread against the source documents. If the overall error rate exceeds 0.3 percent (30 erroneous records in 10,000), the tape is rejected and returned to the contractor. Fortunately, we have found that after the first few months of a contract, the "training curve" levels off, and the acceptance rate is high.

Loading of the automated descriptive data into the NGS data base began in July, 1978. During the loading process, additional edits are performed and necessary updates, deletions, or corrections are made. The descriptions are logically merged with the positional data for each station, and automated data sheets for publication are produced (Pfeifer, *ACSM Bulletin*, No. 61, May 1978). Under the new data base environment, update, maintenance, and retrieval of descriptive information will be easier and faster. The end result will be a quality product and timely service to all users of geodetic data. ■

Article No. 15

Deflections of the Vertical

by Charles R. Schwarz
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NOS, NOAA, Rockville, Md.

Most existing horizontal geodetic datums, including NAD 1927, have been computed by the development method. This means that differences between the geoid and ellipsoid are completely neglected. In effect, the geoid and ellipsoid are taken to be synonymous. Measured distances reduced to sea level, i.e., to the geoid, are assumed to lie on the ellipsoid. Theodolites leveled in the real gravity field of the Earth, i.e., oriented along the astronomic normal or plumb line, are assumed to be oriented along the ellipsoidal normal.

The development method, by ignoring the differences between geoid and ellipsoid, leads to errors in adjusted coordinates. These errors are reflected as distortions which tend to persist over areas of several hundred kilometers. Minimizing these distortions associated with the development method has historically been the reason geodesists have attempted to determine an ellipsoid which best fits the geoid. If the chosen ellipsoid fits well to the geoid in the area of consideration, then the distortions will be small.

The alternative to the development method is the projection method. Both the geoid height and the deflection of the vertical must be known at every occupied control point, and directions and distances are properly reduced to the ellipsoid. A well fitting ellipsoid is no longer necessary, since the proper reductions are no longer neglected.

The new adjustment of the North American Datum (NAD) will be based on the projection method. An extensive effort is underway to compute the deflection of the vertical at each of the approximately 160,000 occupied points in the network. Precise geoid heights will be obtained as an almost incidental byproduct of the computation of the deflection.

The computation method is a numerical quadrature using the classical Stokes and Vening-Meinesz equations. The method requires a detailed free-air anomaly field with 45' (minutes of arc) of the control point and mean gravity anomalies farther away. This method has been selected as being consistent with the accuracy goal of 1" or 2" (seconds of arc), the finite computer resources available, and the available data.

Within the United States, astronomic positions will be measured directly at nearly all National Geodetic Survey (NGS) stations where there is an actual or potential line of sight with a vertical angle of 7° or greater. For lines with vertical angles of less than 7°, the following analysis confirms our strategy. Propagating an error of 2" into the correction to horizontal directions for deflection of the vertical

$$\Delta\alpha = (\xi \sin A - \eta \cos A) \tan \beta$$

and assuming $\beta = 7°$ shows that the maximum propagated error in a horizontal direction is 0".25. This is well below the accidental error component of first-order directions.

Computing the deflection at all occupied points, using both astronomic and gravimetric deflections, will not only serve the NAD new adjustment, but will also enable NGS to make deflection values available as part of the published data at each station. The deflection accuracies should support most anticipated applications.

The process of deflection prediction uses five data bases. The first three are collected and organized sets of mostly existing data. The last two sets are computed from the first three.

The first data base contains approximately 1 million gravity anomalies in the United States, offshore, and border areas. Major sources of gravity data are the land and offshore files of NOAA's National Geophysical and Solar Terrestrial Data Center. The land file contains the nonproprietary data of the Defense Mapping Agency (DMA) Aerospace Center. To these major sources we are adding the results of NGS gravity surveys and a variety of other sources. Our objective is to achieve a density distribution of at least one gravity station in every 5' square. We already have this density in most regions and expect to complete the data base without performing any surveys exclusively for this purpose.

The second data base contains approximately 14 million topographic heights covering the entire United States. These were derived from the digital topographic data originally prepared by the DMA Topographic Center by digitizing the contours on 1:250,000 scale maps. Our 14 million points are located at 30" grid intersections.

The third data base is the NGS holdings of almost 5,000 astronomic positions of first- and second-order quality. Most of these are recent, and more than half were established in connection with the Transcontinental Traverse project. For the NAD new adjustment, approximately 100 new astronomic positions are being observed. The stations selected have vertical angles of 7° or larger.

As an aid in the interpolation of point gravity anomalies, we perform surface fitting to the anomalies within each 30' square. These are saved in a fourth data base.

The last data base contains mean gravity anomalies computed from the point anomalies. These are organized into subsets of 5', 15', and 1° squares. Our processing system was applied in the White Sands area of New Mexico. This area contains an abundance of astro-geodetic deflections. Furthermore, the gravity field in the area is sufficiently rough to provide a good test of the accuracy of our prediction method in mountainous areas. We predicted 441 deflections using 178,986 point gravity anomalies and 6,004,398 point elevations. The table below indicates the comparison between the observed astro-geodetic deflections and those predicted by gravimetric means.

Component	Observed astro-geodetic deflection			Gravimetric deflection
	min.	max.	rms	rms discrepancy
ξ	-13.″1	6.″1	2.″7	0.″9
η	-12.″5	29.″8	6.″3	1.″3

These results indicate that the accuracy goal of 1" to 2" is being met, and that the error in horizontal directions due to deflection errors will be kept well below the observational error.

Determining the deflection of the vertical at all control points will be a major computational effort—almost comparable to the adjustment of the network itself. However, there are two major reasons for this effort. First, it will be possible to perform the new NAD adjustment in a manner that has no detectable distortions due to neglect of the separation between the geoid and the ellipsoid; and second, after the adjustment, geoid heights and deflections at horizontal control points will be available to all surveyors. ■

Article No. 16

Publication and Distribution of Adjustment Results

by John F. Spencer

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National Geodetic Survey
NOS, NOAA, Rockville, Md.

Successful completion of the future North American Datum 1983 (NAD83) will depend on three interrelated tasks: data gathering, data processing, and data distribution. Previous articles in this series have dealt with data gathering and processing activities. This article addresses the publication and distribution of NAD83 results.

Publication

The goal of data gathering and data processing activities is to produce adjusted network results and to subsequently depict these networks on geodetic control diagrams. To assure that these results will be published and available to the user immediately upon completion of the NAD83 redefinition, computer technology, micrographics, laser printing techniques, and distributed processing activities which transform these adjusted results into a marketable user product are actively being investigated today.

What are the criteria under consideration? Why is it not possible to simply output the adjusted results, prepare the data for the print shop, publish them as 30' quads, and distribute the product to the users? To answer these questions, consider the following scenario. Since the last general adjustment in 1927, the growth of the geodetic file has increased tenfold. The original published NAD27 contained 25,000 points. It has gradually increased by extension and densification to a 250,000 station network. The proposed NAD83 will contain a large majority of these points plus an approximate 27,000 additional stations. Based on samplings of computer-generated data sheets published in the 30' quad format—similar to the illustration depicted in Article 11 of this series (Pfeifer, *ACSM Bulletin*, No. 61, May 1978)—an average of 2¼ pages of published data is required for each station. Therefore, one set of the NAD83 published results would involve approximately 549,000 pages of computer output. By measuring 200 pages per in., a filing facility large enough to store 229 linear ft. of data would be required. This is equivalent to 16 file cabinets with the following dimensions: 6 ft. height, 3 ft. width, and 1½ ft. depth. These 16 file cabinets would only be able to contain one set of the NAD83 published results. If we were to print the same average number of copies of NAD83 as in the past for projects being adjusted to NAD27, 9 mi. of data (110 million pages) would be required. The direct and indirect printing costs to publish these data, using 1978 figures, would amount to $2.2 million. Therefore, we must investigate alternative methods.

Alternative methods include micrographics, laser printing technology, and distributed processing (telecommunication) activities. The technical and operational developments investigated over the last five years cannot possibly be covered in the scope of this article. However, the following anticipated benefits are envisioned by the future application of these methods.

Computer-generated micrographics (reformatted digital data output onto microform) generally reduce output generation and material costs. The largest cost savings are realized by reduced physical storage and data handling. For example, to store the entire NAD83 results, only half of one cabinet, instead of the previously mentioned 16 cabinets, would be needed.

Laser printers are available today which run at speeds ranging from 2,000 to 20,000 lines per minute. With such rapid speeds, it would be possible to print the entire NAD83 in less than two days. By 1983, this time period may be shortened to several hours instead of days. Today, an average size 30' quad (110 pp.) of data can be printed in about 30 seconds. In 1983, it may take only a few seconds. Again the derivable benefits would be reduced storage and handling costs, and high-quality output. The new laser printer is excellent for demand printing. Since the National Geodetic Information Center furnishes data only upon request, this technology would eliminate the need for mass printing, storage, and data handling. Manual file maintenance and data retirement would be eliminated.

Distributed processing will emerge with the availability of data in digital form and the application of continual future developments, as discussed above. Organizational data exchanges and regional availability of NAD83 will be commonplace in the information network of the mid-1980's.

Without computer technology the ongoing New Adjustment would be impossible, as would new information processes. The primary advantage of computer technology is flexibility, which, in this case, provides diversified products and customized services to the user.

Distribution

Prior to the last general adjustment in 1927, users of control data were primarily in the surveying, mapping, and engineering professions. In addition to these traditional fields, the results of the NAD83 will be distributed to a myriad of users, because of the demands of our finite natural resources, development of sophisticated navigation and weapons systems, technological advances in geodynamics, and the establishment of related data banks for better management of land and coastal zone uses. The following list exemplifies the present wide application of geodetic control survey data:

- All surveys and negotiations for national and international boundary definitions, including the individual states and their political subdivisions.
- Photogrammetric densification and new technologies such as satellite positioning and inertial surveying systems.
- Planning, engineering, and construction activities for rural, urban, and regional development.
- Nationally coordinated transportation systems involving air, rail, or highway.
- Utility and energy assessment studies.
- Mining and other geophysical surveys, including offshore exploration.
- National and international navigation systems (positioning).
- All mapping and charting work.
- Environmental and ecological studies.
- Agricultural programs.
- Military operations.
- Land-use and recordation management systems (cadastre).
- Fire and police surveillance systems.
- Crustal movement and seismic activity studies.
- National resource inventory and management.
- Aerospace activities.

User requests for geodetic information are processed at an average rate of eight per hour. Requests vary from one geodetic control diagram or one quad of data to diagrams and data coverage by state areas or, in very rare cases, the entire United States. These requests are received from the following sources: commercial and private industry, 37%; federal agencies, 33%; state and local agencies, 24%; general public, miscellaneous, 6%.

While geodesists and computer specialists are actively gathering and processing data in preparation for the New Adjustment, information specialists are actively planning for the publication and distribution of the NAD83 final results. The projected "due date" of 1983 is fast approaching, and shortly thereafter the user should receive a quality product, available in several publication media at a reasonable cost. ■

Article No. 17

Datum Parameters

by Captain John D. Bossler

Deputy Director
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It has been brought to my attention that none of the other articles in the adjustment of the North American Horizontal Datum series details the datum to which the coordinates will refer. This article describes the requirements for a datum and the reasoning behind the decisions that have been made for NAD 83.

To locate or fix a point in three-dimensional space, it is necessary to define a coordinate system. A three-dimensional coordinate system can be defined by selecting an origin and the direction of each axis, i.e., a total of six parameters consisting of three coordinates and three angles. Such a coordinate system could be called a datum.

In geodesy we use additional parameters—the dimensions of an ellipsoid—to assist us in locating or establishing coordinates and in defining a datum. Because the Earth or, more precisely, the geoid closely approximates an ellipse which has been revolved around its minor axis, we use an ellipsoid as a reference figure. (For a discussion of the relationship between the geoid and the physical surface of the Earth, the reader is referred to *Geodesy for the Layman* (Burkard, 1968). The ellipsoid itself requires that two parameters be defined, usually the semi-major axis (a) and the flattening (f). It can also be defined by the semi-major axis (a) and the semi-minor axis (b). To many control surveyors ellipsoid is synonymous with datum, although, as explained, the definition of a datum usually requires at least six additional quantities. Most of us are aware that the North American Datum of 1927 is based on the Clarke 1866 ellipsoid and that the European Datum of 1950 is based on the International (Hayford) ellipsoid. Both datums are being redefined. Although the definition of a datum usually requires more than the eight parameters mentioned, e.g., the height of a particular point above or below the ellipsoid, etc., this article considers only the six parameters mentioned above.

Theoretically, the first six parameters, along with a yardstick for scale, clearly would be adequate to determine the location of a point on a stable Earth. However, the local horizontal, defined as perpendicular to the direction of the plumb bob, is somewhat necessary and convenient in surveying procedures for several reasons. First, three-dimensional positioning devices are just now becoming commercially available at affordable prices. Second, a common reference, the horizontal, is a practical requirement for the description of land parcels and for construction and engineering surveys. To aid control surveyors in establishing horizontal points (latitude and longitude), the ellipsoid, as stated, closely approximates the shape of the geoid, and therefore, it is used as the reference surface. The phrase, "closely approximates the shape of the geoid," leads into one of the main thoughts in this article.

If the size and shape of the ellipsoid closely approximate the geoid, we can neglect the differences between the reference figure and the geoid. If this condition is optimized globally, it will not be optimized locally. The latter has been the primary consideration in the past when datums were defined. As discussed in article 15 of this series (Schwarz, 1979), the effects of geoid heights and deflections of the vertical will be accounted for fully in the new adjustment of the North American Datum. Because the differences between the geoid and the ellipsoid, no matter how large, will be accounted for and not neglected, one must reconsider the problem of defining a datum. Most recent datums have been geocentric, i.e., the center of the reference figure coincides, as closely as measurements allow, with the center of mass of the Earth. The Defense Mapping Agency (DMA) of the Department of Defense (DoD) defined such a datum in 1972, identified as WGS 72. This datum has been used extensively by the world mapping and charting community. One of the main reasons for a global datum is increased global applications both for civilian and defense purposes. There are only a few disadvantages of a globally best-fitting datum. For instance, one may assert that a larger separation of the geoid from the ellipsoid will result from a geocentric datum. While this is true, we still need to examine the problem. In the conterminous United States, the *change* in the separation of the geoid and ellipsoid for a global datum, as compared with the NAD 27, will be a maximum of about 35 m. Because this affects the reduction of distances by an amount approximately equal to 35/6,378,135, or 1/180,000, this quantity concerns only those of us involved in extremely accurate surveys. It is probably fair to speculate that at least 90 percent of the U.S. surveying community could ignore this error for nearly all of their surveys. Certainly, it is true for surveyors involved in lot surveys, subdivision layout, and similar activities.

Considering the global applications and weighing all considerations carefully, the countries involved in the project formally have decided that the NAD 83 would be a geocentric datum, or best fitting in a global sense. This decision means that the center of the ellipsoid must coincide with the origin of the coordinate system—the center of mass. But how do we define the origin? Fortunately, we have the means to accomplish this. The orbits of the Navy Transit satellites have been determined by DoD, and Doppler signals from these satellites are used when one determines positions using Doppler receivers. If the orbit is considered to be known, then positions referred to the orbit are determined. These positions are, to a very close approximation, referred to the center of mass of the Earth, because the orbit of a satellite is clearly referenced to a mass center. By including the geocentric Doppler positions in the adjustment, the datum will be referenced to the center of mass of the Earth. The directions of the coordinate axis of our datum can be determined by defining a pole and reference for longitude.

In space, the direction of the rotational axis of the physical Earth is not invariant with time. There are many reasons for this condition. (See Mueller (1969) for a complete discussion.) Here, we need to consider only the relationships between the instantaneous axis of rotation (pole) of the Earth; the axis of the reference figure, which is the semimajor axis of the ellipsoid (*b*); and a mean or established direction of the axis of rotation. A successful orientation of the datum would be accomplished if we make the axis of the ellipsoid coincide with the mean value of the axis of rotation (mean pole). This orientation has also been agreed upon by the countries involved in the NAD project. How do we accomplish this?

Again, we have a solution at hand. NGS has been observing polar motion, which is the difference in direction between the instantaneous axis of rotation and (*b*), for more than 75 years. These optically observed values have been combined with values from other countries by several international organizations that publish the positions of the mean pole. All pertinent data in the adjustment will be referred to the mean pole and, therefore, our datum will be so oriented. Defining the direction of the pole fixes two of the three required angles. The third is defined by adopting a zero longitude. We have agreed to orient the datum by referencing our zero longitude to the Greenwich meridian.

The International Association of Geodesy (IAG), a body of the International Union of Geodesy and Geophysics, has agreed to adopt new dimensions for the reference ellipsoid. The formal agreement will be executed in Canberra, Australia, in December 1979. Meanwhile, a study group of the IAG has been studying the results of recent determinations of (a) and (f). The best values for a range $a = 6{,}378{,}135$ m to $a = 6{,}378{,}140$ m. The present uncertainty, Δa, is less than one-half of the range shown. A change in position of a point on the North American Continent, resulting from a change, $\Delta a \leq 2$m, will be less than 0.01 m. Relative positions will change even less. The value for f, $f = 1/298.257$, has already been accepted at the required level of accuracy. For most surveying purposes, including geodetic applications, determining the dimensions of the reference ellipsoid is more of an interesting scientific experience than a practical concern. Future articles in this series will discuss other aspects of the datum.

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Article No. 18

Status of the New Adjustment in Mexico, Central America, and the Caribbean Area

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Since 1946, the Defense Mapping Agency (DMA) has been participating with Mexico, Central America, and Caribbean countries, through a collaborative program under the Inter American Geodetic Survey (IAGS), for the production of cartographic, geodetic, and geophysical products. The horizontal survey network that developed from these agreements consisted of 1,884 stations established by first-order triangulation and traverse methods. Observations among these stations included 9,970 directions, 82 Laplace azimuths, 55 base lines (Invar and Geodimeter), and 4,000 km of traverse.

Positions of the stations were computed by DMA in terms of the North American 1927 Datum (NAD 27) from border ties with the United States. The adjustments were carried out in successive blocks from Mexico to Panama. The lack of an adequate geoid profile prevented the reduction of lengths to the ellipsoid. The adjusted values provided to the individual countries were the best available at that time.

The majority of the elevation control in the network is based on trigonometric observations between stations. Over 50,000 km of first- and second-order geodetic leveling were established to control this trigonometric network.

The Mexico-Central America-Caribbean network, like those of the other North American countries, must be strengthened and readjusted to meet today's engineering and scientific accuracy requirements. To strengthen the network, new first-order surveys are being added by Mexico to tie together gaps in the existing triangulation arcs. Doppler-derived coordinates are being established throughout the network on existing stations at an average spacing of 200 km between Doppler stations. The Doppler positioning is being carried out by the single point positioning method, using the precise ephemerides generated by DMA. An average of 40 usable passes is being acquired at each station. The accuracy of these Doppler positions is less than 1 m, 1 sigma, in each coordinate axis. Most of the Doppler observations, required to control the network, have been completed.

DMA is currently participating in the 1983 readjustment of the North American horizontal networks by processing the control surveys being established in Mexico and readjusting the existing networks established through the IAGS. The work is being coordinated with the U.S. National Geodetic Survey (NGS) and each country through DMA IAGS.

Most of the previously processed horizontal observation data for the area exists in machine-readable form from earlier adjustment. DMA is currently retrieving these data, reformatting the data for computer processing, and performing preliminary adjustments for analysis of these data. Observation data not in machine-readable form, but required as an integral part of the triangulation arcs, are presently beng coded, key-punched, and processed from files for inclusion into the final adjustment.

A geoid profile is also being constructed to cover Mexico, Central America, and the Caribbean. Upon completion of the geoid profile, all observation data will be properly reduced to the ellipsoid computational surface. Predictions for the deflections of the vertical and geoid heights for each station to be included in the adjustment will be made in a least-squares sequential or stepwise collocation adjustment. Present plans call for the following heterogeneous data to be used in this collocation adjustment:

1. Goddard Earth Model (GEM) 10B;
2. 1,693 1° by 1° mean free-air gravity anomalies;
3. GEOS III satellite altimetry-derived geoid heights;
4. 73,512 point gravity observations;
5. 83 Doppler-derived geoid heights;
6. Observed deflections at 96 astronomic stations.

In a test of the stepwise least-squares collocation program at DMA, the standard error of predictions in geoidal heights was within ± 0.30 m, while standard error of predictions in vertical deflections ranged within ± 2″.50. Based on these results and the above data types, prediction errors at the Mexico-Central America-Caribbean stations will be small enough to permit reduction of horizontal observations to the ellipsoid with the required accuracy.

At present, over 90 percent of the horizontal observation data located in DMA files have been processed and a successful preliminary least-squares adjustment of these data has been completed. Thirty-one Doppler-derived positions were used to control the network. Positions were computed in the World Geodetic System 1972 (WGS 72). It is assumed that the Earth-centered coordinate system selected for the 1983 datum will approximate WGS 72. Results of the adjustment indicate the overall quality of the network meets first-order accuracy specifications. Of the 10,333 observations used in this preliminary adjustment, only 35 appeared questionable through analysis of the least-square normalized residual distribution. Final rejection of observations will not be made until all investigations into systematic errors in the observation data have been completed.

[ACSM *Bulletin*, no. 68, Feb. 1980, p. 21]

The present schedule calls for the Mexico-Central America-Caribbean portion of the North American network to be completely processed by October 1980. These processed data will be in the standard NGS format for forming blocks in the combined redefinition and readjustment of the North American horizontal networks to be completed at NGS. However, before furnishing the data to NGS, DMA will perform an adjustment of the network as a single block.

By strengthening the Mexico-Central America-Caribbean network with additional field surveys, properly reducing the horizontal observations to the ellipsoid, and introducing Doppler positions into the network, the combined simultaneous adjustment will yield a rigorous framework of geodetic control for future use by each of the countries. ■

Article No. 19

Status of the New Adjustment in Canada

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Geodetic Survey of Canada is coordinating Canada's participation in the new adjustment of the North American horizontal networks. As currently planned, the adjustment of Canadian networks will be done in three steps. The primary network will form part of the continental network to be adjusted by the Helmert block method. The adjustment of secondary networks will form the next step, with the primary networks held fixed. Some of the better secondary networks may be included with the primary in the simultaneous continental adjustment. The third step will be to recompute lower-order surveys. The second and third steps, the adjustment of secondary and lower-order control, will be done in cooperation with various provincial and other federal control survey authorities.

Geodetic Survey is responsible for the primary network that will form part of the continental adjustment. The Canadian primary network consists of about 5,800 stations and 37,000 observations, and is made up mainly of first-order surveys with some second-order surveys. The network currently consists of:

37 500	km chain triangulation
5 000	km traverse
240 000	km² area triangulation
	310 aerodist stations
8 000	km² urban densification
	169 stations of the basic satellite Doppler network
	327 stations of satellite Doppler densification.

Since the beginning of the program in 1972, about 600 lengths and 50 Laplace azimuths were measured to strengthen the existing triangulation. About 15 more Laplace stations remain to be reobserved. The primary network was further strengthened and extended by first-order traverse and by the addition of a basic satellite Doppler network having stations spaced from 200 to 500 km across the country. The semi-short arc method of satellite Doppler positioning was used, yielding a standard deviation of about 0.5 m between stations.

Although the primary network is considered to be ready for adjustment, new first-order densification surveys, such as triangulation for urban control and satellite Doppler stations at 80-km spacing to control second-order surveys, are being added to the primary network as they are completed.

The geoid, which was not taken into account in the 1927 North American Datum (NAD), will be computed in the new adjustment to apply corrections to measured lengths and directions. It is planned that a Goddard Earth Model, such as GEM10, will be used to compute corrections to lengths and that GEM10 in combination with local gravity and astronomic deflection measurements will be used to determine corrections to directions. In mountainous areas, topographic-isostatic methods may be employed to help determine deflection of the vertical. The accuracy (standard deviation) of the proposed geoid is estimated to be 1 m in height and 1.5 sec. in deflection, except in the mountains, where it is estimated to be 1.5 to 2.0 m in height and 2 to 3 sec. in deflection.

Two preliminary adjustments of the primary network have been computed, and another is planned for 1980. There were 65 outlying observations in the first adjustment, and this dropped to 22 in the second. The first preliminary adjustment was computed on an approximation of the present 1927 NAD, the second was computed on our best approximation of the 1983 NAD, and the third is to be on the final 1983 datum. This third preliminary adjustment is to be used to begin mapping on the new datum.

In the continental adjustment, the Geodetic Survey will compute the Canadian blocks, reducing them to the junction stations selected along the international boundaries, plus the basic satellite Doppler stations, which will also be treated as junctions. Both the Geodetic Survey of Canada and the U.S. National Geodetic Survey (NGS), NOS/NOAA, are to compute the solution for the common junctions, including the satellite Doppler stations. To participate in the adjustment in this manner, the Canadian adjustment software is being modified and some NGS software is being included to produce a system compatible with the NGS system.

There are an estimated 109,000 secondary and 112,000 lower-order stations in the country. The Canadian Geodetic Survey will be responsible for the secondary and lower-order adjustments in the Yukon and North-West Territories, and will assist the provinces as required. Preparations for these steps in the NAD83 adjustment are underway now, and it is hoped that the secondary surveys will be ready for adjustment as soon as the continental adjustment is completed. It is possible that the secondary surveys will be adjusted simultaneously, but it is more likely that the work will be done province by province, with mutually agreed common boundary stations. Lower-order surveys will be integrated as required, and some of these surveys may be computed by an approxmiate method now being developed and tested.

The completion of the new adjustment in Canada will result in survey control of higher and more dependable accuracy, better able to meet today's requirements. It will also mean that mapping and geocoded data files must be amended to take into account the expected shifts of up to about 120 m in geodetic position and up to about 230 m in UTM coordinates. ■

Article No. 20

Status of the New Adjustment in Greenland

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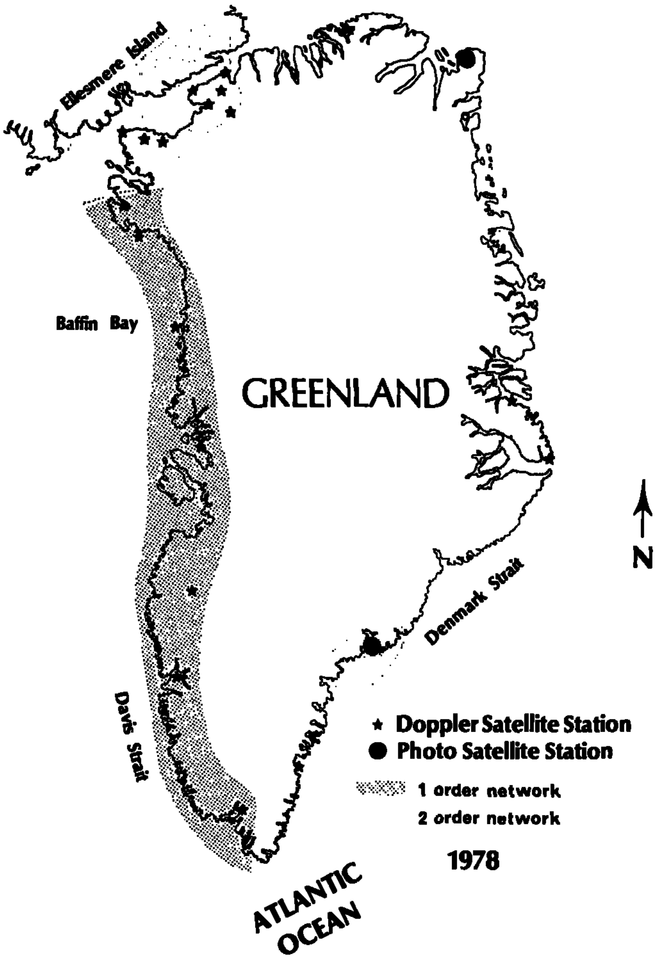
Shortly after the New Adjustment of the North American Datum began in 1974, the National Ocean Survey suggested that the geodetic networks in Greenland should be included in the project. The responsibility for implementing this suggestion fell to the Danish Geodetic Institute, since Greenland was at that time an administrative district of Denmark. (Greenland became a self-governing community in 1979.) Historically, the geodetic control in Greenland has been carried on local datums, the European Datum, and the North American Datum. These networks are included in the new North American Datum, both because Greenland is geologically a part of the North American Continent and because there exist direct survey ties between Greenland and Canada.



First- and second-order networks in Greenland.

Activities undertaken at the Geodetic Institute have included the selection of the measurements to be included in the new adjustment, a number of position determinations using Doppler satellite observations, geoid determinations, and experiments with the Helmert blocking technique.

The geodetic control in Greenland may be divided into two areas: those regions covered by classical triangulation and trilateration, which were established during the last 50 years, and those areas where geodetic control has been obtained in recent years by the Doppler satellite technique (*see* figure).

A first-order network exists along the west coast of Greenland approximately from latitude 60° to latitude 77°. The single chain network consists of about 200 stations. All types of geodetic measurements, including directions, distances, and Laplace azimuths, have been performed according to first-order standards. The observations are adjusted on the Qornoq Datum, which originally was a local datum for the central part of the west coast of Greenland. Extensions have been established to southern Greenland and northwestern Greenland. This latter network was adjusted with the cooperation of the Marine Science Directorate, Canada. Additional independent network adjustments were performed at two places on the east coast of Greenland, but the lack of geodetic connections to the Qornoq Datum forced both areas to be established on separate datums, i.e., the Angmagssalik Datum and Scoresbysund Datum.

Densification of all the primary networks has been performed from time to time. It was decided that all observations that would improve the accuracy of the existing networks would be included in the new adjustment. All observations are in computer-readable form. The total number of stations are now estimated to be 4,300.

The use of the Doppler satellite surveying technique serves two main purposes: to support the connection of the existing network to the North American Datum 1983 (NAD83) and to establish geodetic control in northern and northeastern Greenland. Since 1974, 16 Doppler stations have been established in the existing networks with an average distance of 300 km between stations. Four of the stations were established in cooperation with the Geodetic Survey of Canada and NOAA/NOS National Geodetic Survey. The remaining stations were surveyed by using the two Doppler receivers purchased by the Geodetic Institute in 1976 and 1977. Thirteen stations exist on the Qornoq Datum, while the Scoresbysund Datum has two stations and the Angmagssalik Datum one station. Probably two or three more stations will be observed before the new adjustment is completed.

Until recently the unsurveyed areas in Greenland covered approximately 300,000 km^2. Geodetic control is now introduced by means of the Doppler satellite technique. The Doppler stations are observed with a spacing of about 60 km, and supplementary control is established using classical traverses. Height control is performed by trigonometric leveling and barometric height measurements. The table shows the number of Doppler stations in Greenland.

Year of Observation	Number of Stations
1976	4
1977	2
1978	22
1979	24

In 1980, we plan to complete the geodetic control by establishing about 35 Doppler stations in the eastern part of northern Greenland.

A geoid covering the ice-free areas of Greenland will be established in order to apply corrections to measured distances and directions. Another application will be the derivation of orthometric heights at stations where Doppler satellite observations have been performed. The method of computation will be by collocation as developed at the Geodetic Institute (Tscherning, 1979). The determination of the geoid employs the best available Earth model, such as GEM 10, in combination with 1° x 1° equal-area mean gravity anomalies as well as local gravity anomalies and geoid heights derived from Doppler satellite observations and mean sea level determinations. Further, topographic corrections will be applied in some areas to improve the accuracy. The standard deviation is estimated to be 1 m in height and 3 seconds of arc in deflection of the vertical.

A preliminary adjustment is scheduled in 1981. We anticipate that the datum parameters will be those of the final NAD83. The adjustment program developed at the Geodetic Institute (Poder, 1978) will be used for the preliminary adjustment as well as for the final adjustment.

Experiments with the Helmert blocking method have been conducted. The approach consists of recursively dividing the network using geographic coordinates in two almost equal parts and a buffer part. The method is very fast and permits interactive operations during the adjustment process.

At the moment only Doppler stations are introduced as junction stations between Canada and Greenland. However, investigations will be performed to determine if suitable junction points can be selected in the network covering the eastern part of Canada's Northwest Territories and the northwestern part of Greenland.

The New Adjustment of the North American Datum will result in more reliable geodetic coordinates in Greenland and is intended to meet future geodetic requirements. We expect that the mapping project of northern Greenland currently being conducted by the Geodetic Institute will benefit from the new adjustment. When the NAD83 definition is available, we hope that the maps will be produced on the new datum.

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Article No. 21

Geodetic Network Diagrams

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Introduction

The first national geodetic control diagram was a project sketch of the geodetic field survey performed in the vicinity of New York City in 1816-17. From this early beginning until the 1840's, horizontal control (triangulation) networks were shown on nautical charts. After that period, until the last general adjustments in 1927 and 1929, geodetic control diagrams were shown as project sketches in the final survey reports.

With the completion of the North American Datum of 1927 (NAD27) and the National Geodetic Vertical Datum of 1929 (NGVD29), tremendous network densification surveys were begun by various governmental and private organizations. The first mass production of geodetic network diagrams occurred in the mid-1930's. They were used then, as today, to assist the user in making specific station selections and to develop plans for future surveys.

When the new adjustment of the North American Datum of 1983 (NAD83) is completed, we can again anticipate tremendous network densification survey activity. Geodetic control diagrams depicting these network results as well as supplementary survey connections will be available to the user by means of computer-assisted cartography. The National Ocean Survey (NOS) is presently procuring an automated cartographic system to accommodate present and future needs for geodetic control diagrams.

Types of Diagrams

Geodetic diagrams provide a basic surveying requirement. Anyone who uses geodetic control data is familiar with the diagram series discussed in Figure 1. With the exception of the National Vertical Control Network diagrams and the state vertical control diagrams, all other geodetic diagrams published by NOS depict the National Horizontal Control Network. That is, from a total of 865 diagrams, 812 depict horizontal control.

A sampling of data recently distributed by the National Geodetic Information Center shows that an average of 1,860 diagrams per month were sent to users upon request or through the automatic mailing service. During the 8-month period assessed, the following geodetic diagrams were distributed to users: 5,081 geodetic control diagrams, 3,073 National Vertical Control Network diagrams, 3,060 National Horizontal Control Network diagrams, 1,612 coastal diagrams, 1,099 state horizontal control diagrams, and 960 state vertical control diagrams.

A general inference can be made from these tabulated results: The amount of density (number of geodetic control points) in an area is proportional to the number of requests for data from that area. In the same vein, a greater density of points means increased difficulty in constructing meaningful accurate diagrams without relying on special scale revisions or diagram inset keys.

Density of Control

Statistics on the density of horizontal control points by geographical areas have risen sharply in recent years. In 1927, 25,000 stations were included in the new adjustment (NAD27) of the 48 conterminous states. The adjustment involved a land area of 3,028,710 sq. mi. (on the average, one station for approximately every 121 sq. mi.). For the forthcoming horizontal adjustment (NAD83), an estimated 240,000 stations will be included. The new network will cover a land area of 3,615,122 sq. mi. (on the average, one station for approximately every 15 sq. mi.). These averages are used only to show the growth of the national horizontal network and area coverages. Table 1 shows the number of stations to be adjusted in each state, the land area of each state, and the average spacing between stations.

When prioritizing a schedule for revising diagrams, density (both in network and population) of an area is an important consideration. Other factors include increased field work, user demand, and socioeconomic pressures. Counterproductive forces that contribute to the lengthy update cycle for diagrams may include factors such as reprogram efforts to support other higher priority projects, austerity measures, resistance to change, and inflation. Under these conditions, only 50 to 60 newly revised diagrams are produced each year. Based on a total of 865 geodetic network diagrams, NOS updates all diagrams on the average of once every 15 years. Unfortunately some diagrams are 20 years out-of-date. Of equal concern is the fact that many of the diagram bases upon which the networks are depicted also are obsolete. Some were developed in the mid-1930's. Accurate bases, which show the present transportation systems, the effects of industrial and population growth, and changes to political boundaries, are necessary. While the NAD83 adjusted results are being published, all diagrams will be revised and printed on new bases in order to reflect the new networks and to depict more accurately the physical accessibility to the marks.

Series	*No. in Series*	*Scale(s)*	*Projection*	*Descriptions*
Geodetic Control Diagrams (1° x 2° Area)	471	1:250,000	Transverse Mercator	Geodetic network depicted on 1° x 2° topographic maps covering conterminous U.S. and Hawaii, showing geodetic control established by federal surveying and mapping agencies and various state and local governments.
Coastal Diagrams (Nautical Chart Bases)	241	Various 1:10,000 to 1:357,000	Mercator	Geodetic network depicted on selected coastal charts covering areas from Maine to Texas; from California to Washington; Alaska (panhandle-Aleutian Islands) Bering Sea Islands; Hawaii.
State Horizontal Control Diagrams	58	Various 1:250,000 to 1:666,000	Modified Polyconic	Geodetic networks (horizontal control) depicted within individual states, combination of states, or parts of states.
State Vertical Control Diagrams	52	Various 1:250,000 to 1:666,000	Modified Polyconic	Geodetic network (vertical control) depicted within individual states, combination of states, or parts of states.
State Diagram Insets (Special Purpose)	24	Various 1:24,000 to 1:250,000	Universal Transverse Mercator	Geodetic network depicted on local aeronautical chart bases for Cincinnati, Houston, Atlanta, Louisville, Chicago; several composed from USGS 7½", 15" topo maps shown as California inserts; and the St. Lawrence Seaway.
Alaska State Diagrams (Aeronautical Chart Bases)	17	1:500,000	Lambert Conformal Conic	Geodetic networks depicted on new aeronautical chart bases covering Alaska, including the Aleutian Islands in 17 sections. This is a new series. The first of the series, Anchorage, has recently been completed. Previous coverage of Alaska has been depicted on photoreduced World Aeronautical Chart bases.
National Geodetic Network Diagrams	2	1:5,000,000	Lambert Conformal Conic	Geodetic networks depiction of conterminous U.S. and Alaska (one for horizontal control and one for vertical control).

Figure 1. Types of Geodetic Network Diagrams.

Table 1. Projected Horizontal Control for New Adjustment of the North American Datum 1983.

*States**	*Stations***	*Land Area (sq. mi.)*	*Spacing Average (one station per no. sq. mi.)*
AL	1,681	51,609	30.7
AK	24,724	586,412	23.7
AZ	3,723	113,909	30.6
AR	2,389	53,104	22.2
CA	15,417	158,693	10.3
CO	2,706	104,247	38.5
CT	2,174	5,009	2.3
DE	541	2,057	3.8
DC	634	67	0.1
FL	10,791	58,560	5.4
GA	7,595	58,876	7.8
HI	2,565	6,450	2.5
ID	2,887	83,557	28.9
IL	3,896	56,400	14.5
IN	2,712	36,291	13.4
IA	2,021	56,290	27.9
KS	3,568	82,264	23.1
KY	2,354	40,395	17.2
LA	5,728	48,523	8.5
ME	4,245	33,215	7.8
MD	4,714	10,577	2.2
MA	5,151	8,257	1.6
MI	3,165	58,216	18.4
MN	5,314	84,068	15.8
MS	3,096	47,716	15.4
MO	3,272	69,686	21.3
MT	2,188	147,138	67.2
NE	2,391	77,227	32.3
NV	2,856	110,540	38.7
NH	563	9,304	16.5
NJ	2,586	7,836	3.0
NM	3,911	121,666	31.1
NY	8,437	49,576	5.9
NC	14,405	52,586	3.7
ND	2,294	70,665	30.8
OH	2,528	41,222	16.3
OK	2,428	69,919	28.8
OR	6,570	96,981	14.8
PA	3,268	45,333	13.9
RI	1,159	1,214	1.0
SC	2,726	31,055	11.4
SD	2,378	77,047	32.4
TN	2,578	42,244	16.4
TX	10,786	267,338	24.8
UT	1,561	84,916	54.4
VT	524	9,609	18.3
VA	6,513	40,817	6.3
WA	9,699	68,192	7.0
WV	983	24,181	24.6
WI	2,994	56,154	18.8
WY	1,349	97,914	72.6
Totals	224,738	3,615,122	16.1

*U.S. territories and possessions not included.

**Station totals extracted from NGS data base as of January 1980. About 15,000 more stations will be added before final adjustment begins.

Future Activities

After performing an extensive study to upgrade the production of geodetic diagrams, a decision was made to procure an automated cartographic system. The system will provide the following advantages:

- support NAD83 and NGVD87 publication efforts,
- reduce the update cycle and increase productivity,
- improve visual product quality,
- eliminate the need for increases in staff personnel,
- provide flexibility for special purpose requests.

The following discussion provides a general overview of the technique NOS will use to produce future diagrams. The most recently acquired base material will be placed in digital form, possibly through a laser scanning process. This information will be stored on magnetic media; off-line on portable disk packs, and backed up on magnetic tapes. All network overlay data will be contained in the National Geodetic Survey data base. The interactive cartographic system will merge the base information and the data for the network overlay. Compilation will begin with this initial merging and end with cartographic "smoothing," using the necessary cartographic data base attributes and system software routines. It is anticipated that the new system should be able to reduce the 15-year update cycle to 2-3 years. Labor costs will be reduced 80 percent while at the same time a more timely high-quality product will be produced. The system hardware will cost about $500,000. Delivery is scheduled for late 1981 or early 1982. If this schedule is met, and the necessary software is written, tested, and documented, the system will be in place awaiting the NAD83 results.

The first diagrams and data will be published for areas with the highest density of control where the demand for data is greatest. By examining the density shown in Table 1, and assuming it will take about 2-3 years after the final adjustment to "publish" all the data and diagrams, it is possible to estimate when the data for certain areas will be available. In general, information on the eastern coastal states will be published first and the Rocky Mountain states last. ■

Article No. 22

Height-Controlled Three-Dimensional Adjustment of Networks

by T. Vincenty

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Adjustments of horizontal observations (distances, directions, azimuths) are traditionally performed on the surface of an arbitrary ellipsoid of revolution. To reduce the observations to the ellipsoid we must know (1) the heights of points with respect to the ellipsoid—not to be confused with heights above sea level—and (2) the direction of gravity at all stations at which theodolite observations took place (Schwarz, 1979). Ellipsoidal heights are obtained by applying geoidal separation corrections to heights above sea level. The direction of gravity is expressed by astronomic latitude and longitude. Since astronomic observations are not made at all stations, an interpolation procedure, often assisted by gravimetric measurements, is needed. If no astronomic values, observed or derived, are furnished, the implied assumption is that they are the same as the corresponding geodetic values, which falsifies the final results to some extent, depending on circumstances.

Instead of computing and adjusting on the ellipsoid we can simply compute in three dimensions, that is, without reducing observations to any computational surface. Then the distance between two points is a segment of a straight line and the direction is as measured in the plane perpendicular to the local direction of gravity at the standpoint. The standard three-dimensional method assumes that vertical angles are included among observations for positioning of points in space. If we choose to fix the heights, we have what I call a height-controlled three-dimensional system.

The familiar X, Y, Z coordinates in the equatorial system hardly need an introduction. They are:

$$\begin{aligned} X &= (N + H)\cos B \cos L \\ Y &= (N + H)\cos B \sin L \\ Z &= [N(1 - e^2) + H]\sin B. \end{aligned} \tag{1}$$

B, L, H are geodetic latitude, longitude (positive east), and height; N is the radius of curvature in the prime vertical; and e is first eccentricity of the ellipsoid. The inverse solution in space is used to compute spatial distance S and astronomic azimuth A between two points. With the auxiliary quantities

$$\begin{aligned} P &= -\sin\phi(\cos\lambda\,\Delta X + \sin\lambda\,\Delta Y) + \cos\phi\,\Delta Z \\ Q &= -\sin\lambda\,\Delta X + \cos\lambda\,\Delta Y \end{aligned}$$

we have

$$S^2 = \Delta X^2 + \Delta Y^2 + \Delta Z^2 \tag{2}$$

$$\tan A = Q/P \tag{3}$$

in which ϕ and λ are astronomic values at the standpoint. Equations (2) and (3) are differentiated with respect to X, Y, Z of both points to give observation equations in which the unknowns are dX, dY, and dZ, the corrections to assumed coordinates. Since one dimension is held fixed, one unknown is eliminated from all observation equations and is expressed in terms of the other two.

The adjustment can be restructured so that the coordinate shifts are expressed in the astronomic horizon plane at each station. Denoting

$$R = \begin{bmatrix} -\sin\phi\cos\lambda & -\sin\lambda \\ -\sin\phi\sin\lambda & \cos\lambda \\ \cos\phi & 0 \end{bmatrix} \tag{4}$$

we have the shifts dx (north) and dy (east) as

$$[dx, dy]^T = R^T[dX, dY, dZ]^T. \tag{5}$$

If in eq. (4) we replace ϕ and λ by B and L, the coordinate shifts will be expressed in the plane of the geodetic horizon. Other equations can be derived to give shifts in the geodetic horizon plane without using functions of B and L at all. Further modifications can be made in order to achieve compatibility with programs of cooperating organizations. Details can be found in the references (Bowring and Vincenty, 1979; Vincenty, 1979a and b, 1980a and b; and Vincenty and Bowring, 1978).

The height-controlled adjustment method is conceptually much simpler than the classical approach. It is more efficient because it avoids numerous trigonometric functions and complicated computations on the ellipsoid. It does not impose any restrictions on the lengths of the lines nor on the extent of the network.

The principles of three-dimensional geodesy as applied to triangulation networks were known a hundred years ago, but their application has been mostly local. This approach can now be applied for computations in the new adjustment of the North American Datum, although in a restricted sense. The final results of the adjustment will be published as geodetic coordinates B and L.

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Article No. 23

Another Look at Helmert Blocking

by John F. Isner
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"Divide and conquer" has been a strategy used by rulers since ancient times to cope with their political problems. Many problems in mathematics are also amenable to the divide-and-conquer technique. One such problem is the new adjustment of the North American Datum (NAD).

In one particular version of mathematical divide-and-conquer, a problem of size N is divided into two independent problems which are identical in form to the original problem, but only half as large. Note that this definition allows each problem of size N/2 to be further divided into two independent problems of size N/4, and so on. In fact, the subproblems may be made arbitrarily small. The result of this process is a set of small, independent subproblems, each of which may be much easier to solve than the original problem. The remarkable fact is that by merely combining the separate solutions to the subproblems, we obtain the same result as if the original problem had been solved in one chunk. In the case of NAD, the large problem is the network adjustment, and the divide-and-conquer algorithm is the method of partitioning observations and unknowns first described by the geodesist Helmert in 1880, commonly known today as Helmert blocking. For a further discussion of the mathematics of Helmert blocking, see the article in this series by Hanson [ACSM *Bulletin*, Nov. 1976].

From a nonmathematical viewpoint, divide-and-conquer algorithms like Helmert blocking are desirable because they give management an unusually high degree of flexibility in the allocation of problem-solving resources. This is the viewpoint of the present article.

Divide-and-conquer problem decompositions of the type discussed here exhibit the structure of an inverted tree. In Helmert blocking, as practiced by the National Geodetic Survey (NGS), the tree is called the "strategy" of the adjustment. The nodes of the tree represent blocks of normal equations, the processing of which corresponds to the subproblems. The terminal nodes are the "first-level blocks," which are formed by computing the contribution to the normal equations from all observations originating inside a small geographical region. The root of the tree is a single "highest-level block." The branches of the tree tell which blocks are combined to form a given higher-level block. A Helmert block adjustment has a "forward course" in which progress moves from the first-level blocks to the highest-level block, and a "reverse course" in which the progress moves in the opposite direction.

In any strategy, more than half of all blocks will belong to the first level. Human activity will center around the formation of first-level blocks and the statistical analysis of residuals at the end of the reverse course. At the higher levels, all work will be done by machine, with blocks being formed from their constituent lower-level blocks (according to the strategy) as those lower-level blocks become available.

There is great potential for concurrency inherent in this scheme. Theoretically, 1,000 first-level blocks could be formed by 1,000 independent geodesists using 1,000 independent computers in no more time than it takes to form a single first-level block. Similarly, the formation of higher-level blocks lying on disjoint paths is independent and can again (in theory) be carried out concurrently. Thus (at least in theory) the N subproblems can be solved in time proportional to log N. This is a characteristic of many divide-and-conquer schemes.

In reality, the computations will most likely be carried out on a single multiprocessor computer with a multiprogramming operating system, which allows a certain amount of true concurrency, but nowhere near the theoretical limit just described. In fact, the machine will probably continue to be in demand for tasks unrelated to NAD, such as payroll, throughout the period of the adjustment. On the human side, fewer than 50 geodesists will be available for the formidable task of forming and analyzing the 1,000 first-level blocks.

The question, then, is how to optimize the use of our problem-solving resources (people, machines) to take maximum advantage of the potential for concurrency inherent in Helmert blocking.

The answer is to be found in the design of adjustment software and the procedures for its use. In the NGS design, the strategy plays a central role in an adjustment. It must be defined and placed in the computer before the adjustment can begin. Progress is recorded in the strategy in the form of a status indicator for each block. A first-level block can be "registered" with the strategy any time the geodesist in charge of the block decides it is "ready." A first-level block is "ready" after it has been created and also after it has been reformed at the beginning of an iteration. This scheme allows the geodesists, who work at different rates on blocks of varying degrees of size and complexity, to work in total independence of one another, maximizing their productivity.

What about optimizing machine resources? To this end, the design includes a program called the dispatcher. The dispatcher can be run at any time. Its purpose is to examine the strategy and indentify the blocks which are ready for processing. For each block so identified, the dispatcher initiates an independent computer task. Such tasks may run in parallel and (upon successful completion) record their progress in the strategy. Since no work is initiated until the dispatcher is run, the NAD project manager may decide to schedule dispatcher runs for late evening or weekends to take advantage of hours when the computer would otherwise be idle and reserve working hours for computer-assisted analysis of results.

Tasks may fail due to data errors, hardware errors, or failures of the host operating system. The adjustment system design is "resilient" in that no such errors are fatal but cause local setbacks in progress at worst. Data errors, for example, are automatically traced to the first level. The geodesist in charge of a block containing an error determines the cause, repairs it, reforms the block and reregisters it with the strategy. This will cancel the results of all higher-level blocks on a path leading from the block in question, but blocks on disjoint paths are unaffected.

The designer of any large-scale system encompassing both human and machine processes is indeed fortunate whenever divide-and-conquer techniques can be applied, but may sacrifice valuable advantages by not exploiting the potential for concurrency in the design. In the case of the new adjustment, NGS has chosen the method of Helmert blocking because of its mathematical and managerial potential. The design of the adjustment system fully exploits that potential. ∎

Article No. 24

An Update on the Base Management System

by David E. Alger

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The National Geodetic Survey (NGS) began developing a data base in 1975 (Alger, ACSM *Bulletin*, August 1976) to support the new adjustment of the North American Datum. Development and implementation of the software system, as well as collection of the data into machine-readable form, were labor-intensive tasks. Entry and update procedures were designed and implemented to edit, validate, and identify the data uniquely prior to storage in the data base. This article updates the status of the NGS data base management system and briefly outlines its structure.

Building the NGS data base is a large complex task which involves the storage of voluminous data, collection of different data elements, and the need to expand elements and functions within the data base environment. To appreciate the volume of data NGS is handling, consider the following: More than 235,000 stations are now loaded in the data base, each with positional information; plus about 4,000 stations also have various types of astronomic observations, and approximately 42,000 contain descriptive geographic information. When the data base is fully loaded, each station description will include descriptive information. In addition, there will be 2.5 million observations of various types associated with these stations.

The data base management system provides the user with a hierarchical prompting system, which allows "menu selection" for formulating data base requests. The interactive prompting is controlled via a text editor. Actual data base transactions are run in batch, where outputs are stored in files until requested by the user. The prompting system is basically tutorial: A first-time user can obtain detailed instructions and the experienced user may precisely select the function to be performed. The system design requires only minimal computer training by the user. The user must possess a registered account, know the log-on procedures for the computer, have access to disk space for storing output, and be familiar with the text editor. Most of this information is available from the computer center. Currently, the system can only be used by NGS personnel, who now process about 300 requests monthly. Once the data base is fully loaded, the number of requests is expected to increase dramatically.

Data Base Prompting System Structure

When a user enters the Prompting System he or she is asked if "instructions" are needed. If the user responds "yes," a menu list appears. Some of the instructions include the following: how to obtain a "User's Guide"; format of retrieval requests, i.e., by MAXMIN, quad, state, etc.; system functions (locating a job, fetching a job, printing a job, etc.); description of the prompting system structure; and various functions and utilities available in the data base environment.

Once general instructions are given, the prompting system guides the user through three levels of menus to achieve the desired function. If the user is uncertain of the selections available, a menu of possible choices at any level in the system can be requested.

Level One: Categories. The prompting system currently has four categories—input, deletion, retrieval, and utility. Retrieval and utility are open to all users; input and deletion are available only to authorized users. This lock-out at the category level provides the first level of security to the data base. The menu selection permits future expansion to other areas without redesigning the system.

Level Two: Subcategories. Once a category has been selected, the user is prompted to choose a "subcategory." These include the following: horizontal (3-card), astronomic, description, statistics, and application products. The user account is also interrogated at this second level before authorization is given to use the input or delete categories. For example, a user may be authorized to "input horizontal" but not "input descriptions." This second check prevents illegal access.

Level Three: Function. In the data base retrieval category, this level presents the user with a list of "output formats." Once the format is selected, the user is provided with a method of defining the area to be retrieved, i.e., MAXMIN, state, quad. An additional menu is presented at level three to provide the user with a number of choices for further specifying the area in a manner appropriate to the output format. The ease with which this additional menu was inserted has proven that the system can also be expanded when necessary without impacting the software design and without confusing the user.

The input and delete categories use the function level to guarantee proper procedures are followed. An example of this type of control can be demonstrated by describing the sequence of events which occurs in the "input horizontal" subcategory. Once the user enters this subcategory, the system locks up the process, under the user's account/initials, until the procedure is completed. During the process several data validation programs (functions) are run in sequence prior to entry of the data into the data base. The prompting system does not allow other users to follow this path until the first user has successfully completed the task. The system allows the original user to enter and leave the system, taking whatever time is needed to complete the process (2 hours or even 2 weeks). No other user may enter this path until the first user has finished. The other paths for entry, retrieval, etc., remain open. If a delay should occur, the offending user's account/initials are displayed so the other users can ascertain the length of the delay.

While executing the functions, the user is prompted for data set names (input or output, depending on function), location of file (disk volume), and other miscellaneous information. If at any time the user needs assistance, the "break" key can be pushed and the operator is given options to continue, to receive instructions, or to exit the system. The user may return to the next level in the system to perform functions in other subcategories or categories. If desired, the user may redirect the batch job prior to execution, have the output printed directly, and select various other options. The user may even elect not to run the job, e.g., for training or demonstration.

The main objectives of the prompting system are to provide a level of security for the data base, a friendly environment for the user, and a manageable system of standard software. At the same time the system guarantees maximum data integrity for all users. ■

Article No. 25

Automatic Mailing Service

by John F. Spencer, Jr., and Nathaniel B. Horn

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A subscriber to the National Geodetic Survey's (NGS) Automatic Mailing Service purchases the latest geodetic data for a specified area and then automatically receives revised information for that particular area as it becomes available. This service relieves the user of the task of checking periodically with NGS to determine whether or not activity has occurred in the region of interest and then placing a separate order for the revised data.

The Automatic Mailing Service was established in 1963, and originally provided data to 500 members, including federal, state, and local agencies, private surveyors, universities, and private industry. During the next 10 years the membership gradually increased, with a total enrollment of 1,200 members in 1973. Since then, the enrollment has grown to the present membership of approximately 3,000, which includes 350 federal agencies, 1,500 commercial users, and 1,150 members from universities, and state and local agencies.

In the past this service was performed by a manual operation. Recently, NGS implemented a computer-assisted system which provides the service in a more accurate and timely manner. The prospects of future enhancements are encouraging because of the availability of automated files and computer resources. The system now contains the following files:

- *Diagram file*—Contains a diagram code and names of the users receiving each diagram.
- *State map file*—Contains the state map code and names of the users receiving each state map.
- *Chart file*—Contains a chart code, the quadrangle areas covered by the particular chart, and names of the users receiving a specific chart.
- *Quadrangle data file*—Contains a quadrangle code and the names of the users who receive geodetic data for that particular quadrangle area.
- *User address file*—Contains the addresses of each user.
- *Price file*—Contains pricing information for generating costs and billing.

The system is supplied with indicators for each revised area showing present membership for a specific area and information on initial orders to new members. When data are revised, or initial orders are to be filled, the input indicators activate the systems's programs to execute the desired result by accessing the above files. The system produces a summary sheet which contains all data items to be extracted for distribution. A pick document is also produced to show every piece of data each customer will receive. Attached to the pick document is a mailing label for the customer and an itemized display of the costs for billing purposes. Updating procedures rapidly facilitate changes in the user's area of interest or a change of address.

During 1984, the National Geodetic Survey is scheduled to complete the new adjustment of the National Geodetic Horizontal Control Network, known as the North American Datum of 1983 (NAD83). The Automatic Mailing Service will provide data from the NGS data base stored in computer-readable form for the entire North American Continent, plus Hawaii and the U.S. territories. A similar process is underway for the National Geodetic Vertical Control Network. The redefinition of the vertical datum will be known as the National Geodetic Vertical Datum of 1987 and is scheduled for completion later this decade. The data base serves as the national depository for geodetic data; the Automatic Mailing Service will provide the mechanism to access these digital files based on subscriber requirements.

When the final adjusted NAD83 results are available, increased membership in this service is anticipated. With direct access to the NGS data base, the National Geodetic Information Center (NGIC) will be able to plan and implement a computerized product that provides printed data on demand. As the transaction files are processed through the Automatic Mailing Service system, NGS will be able to produce statistics showing the current frequency of usage. This will enable us to forecast costs more accurately and assess the benefits on a national level as we prepare to print and distribute the NAD83 results.

If you wish to subscribe to the Automatic Mailing Service, complete NOAA Form 29-3, "Geodetic Control Data Automatic Mailing Service Agreement," reproduced on the following two pages and mail to the address shown on the form. Explanatory information and prices appear on the reverse side of the form.

After NGIC receives your completed mailing agreement, your requirements will be entered into the system and you will begin to receive geodetic file updates for your area of interest. Furthermore, when the NAD83 results are available for your area, you will automatically receive them without further correspondence.

For further information, contact: Director, National Geodetic Information Center, OA/C18, National Oceanic & Atmospheric Administration, Rockville, Md. 20852. Phone (301) 443-8631.

NOAA FORM 29-3
(8-81)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

CUSTOMER ID NUMBER
(For Agency Use)

GEODETIC CONTROL DATA
AUTOMATIC MAILING SERVICE AGREEMENT

INSTRUCTIONS – Complete items 1 – 6 and return to the National Geodetic Information Center, OA/C18, National Geodetic Survey, National Ocean Survey, NOAA, Rockville, Maryland 20852.

1. APPLICANT'S NAME AND ADDRESS

TELEPHONE NO. AND AREA CODE

2. Indicate below the types of data desired. If you require more than one copy of any item checked, indicate the number of copies needed.

✓	GEODETIC CONTROL DATA	NO. OF COPIES	✓	GEODETIC CONTROL DATA	NO. OF COPIES
	Horizontal Data – 30' quadrangle booklets			Vertical Data – 30' quadrangle booklets (or level line format in certain areas)	
	Horizontal Data Projects (Manuscript form)			Vertical Data Projects (Manuscript form)	
	Horizontal Control State Diagrams			Vertical Control State Diagrams	
	Geodetic Control Numbered Charts or City Insets			Geodetic Control Diagrams (1° x 2°)	

3. INDICATE AREA TO BE SERVICED BY PROVIDING REQUIREMENTS LIST, A DETAILED DESCRIPTION, OR A SMALL ATTACHED MAP *(e.g., states, counties, 30' quadrangle areas or latitude and longitude boundaries).*

4. ☐ Check here if the applicant desires an initial shipment of above requested data. The purpose of this shipment is to establish an initial file for new subscribers.

5. **AGREEMENT** – The applicant agrees to accept all requested geodetic control data and to pay for the same upon receipt. Prices will be based on the current price list.

6. AUTHORIZED OFFICIAL *(Applicant)*	NAME	TITLE	
	SIGNATURE		DATE
7. ACCEPTED BY NATIONAL GEODETIC SURVEY	NAME	TITLE Director, National Geodetic Information Center, National Geodetic Survey, NOS, NOAA	
	SIGNATURE		DATE

NATIONAL GEODETIC SURVEY
GEODETIC CONTROL DATA USER–CHARGE SYSTEM

(Effective September 1981)

GENERAL INFORMATION

The national network publications of geodetic control data are primarily represented by standard quadrangles of 30' of latitude by 30' of longitude. However, in congested control areas, standard quadrangles are 15' of latitude by 15' of longitude and in some cases 7½' of latitude by 7½' of longitude. Field data and recently adjusted projects in manuscript form are available upon request. Diagrams which depict the location of geodetic control stations are available for most areas of coverage.

Federal Government agencies may be furnished a complimentary copy of these data for their jurisdiction as required.

DATA FOR SURVEYS BY OTHER ORGANIZATIONS

Control survey data in NOAA publications may result from field surveys by other organizations. When field observations are performed to NOS standards and data are evaluated and adjusted by NGS, the resultant data are included in the national network publications.

NOAA publishes and distributes supplemental data for control surveys by other organizations that are not evaluated or adjusted by NGS. These publications are reproductions of data prepared by the establishing organization and assembled in the adopted NOAA quadrangle units.

COMBINED HORIZONTAL AND VERTICAL DATA

The horizontal and vertical geodetic control data are normally published separately. However, certain supplemental surveys by "other organizations" are being published and distributed by NGS in which horizontal and vertical data are published together on the same data sheets. For simplicity, these data are assembled and priced under horizontal data.

AUTOMATIC MAILING SERVICE

The NOAA Geodetic Control Data Automatic Mailing Service Agreement provides the mechanism through which users maintaining active files receive newly published data automatically for a specific area. To facilitate this service, it is necessary that the desired area be requested by complete quadrangle units.

The prices for initial data furnished through the automatic mailing service are the same as for individual orders. Revised data for the requested quad will be automatically furnished thereafter for a charge based on the number of sheets mailed (not to exceed $28.00 per quad). It is necessary that a copy of each charge statement accompany payment to ensure proper credit. There are no additional service charges or membership fees.

All subscribers to the automatic mailing service are required to execute a "Geodetic *Control Data Automatic Mailing Service Agreement" and return it to:* The Director, National Geodetic Information Center, OA/C18, National Geodetic Survey, NOS, NOAA, Rockville, Maryland 20852. A copy will be returned to the applicant indicating the action taken by this organization.

CHARGES AND BILLING

A minimum charge of $2.00 will be made for all orders. Prepayment is required for all orders which exceed $100.00 unless they are a product of the automatic mailing service. The standard charges for geodetic control information are as follows:

1. Published quadrangle booklets – horizontal or vertical control:	
1 thru 20 sheets, per booklet	$2.00 each
21 thru 50 sheets, per booklet	$6.50 each
51 thru 100 sheets, per booklet	$14.00 each
101 or more sheets, per booklet	$28.00 each
2. Complete county coverage – horizontal or vertical control: Old format data not presently available in published quadrangle booklets	$4.00 each
3. Manuscript form – horizontal or vertical control: Unadjusted project data or recently adjusted projects in process of being incorporated into quadrangle booklets.	
1 thru 20 sheets, per project	$2.00 each
21 thru 50 sheets, per project	$6.50 each
51 thru 100 sheets, per project	$14.00 each
101 or more sheets, per project	$28.00 each
4. Geodetic diagrams (regardless of size or area covered)	$5.00 each

The above prices include postage and handling costs.

NOAA provides other related geodetic information, i.e., gravity values, astronomic positions, satellite-derived positions, horizontal and vertical control crustal movement data, and calibration baseline information. In most cases, these data are available on magnetic tape and/or paper. New micro-publishing techniques are being introduced in the form of computer-generated microforms and certain geodetic data are available on microfilm or microfiche. Charges for computer-generated information are determined on an individual request basis and reflect processing time, materials, and postal costs.

As an additional service, NOAA provides computer programs, reference materials (*technical reports, manuals, special publications*), cartographic products and consulting services pertaining to geodetic science on a cost recovery basis.

Secondary and tertiary information products such as the NOAA Geodetic Newssheet, information brochures and pamphlets, and diagrams depicting the status of the national control networks are provided free upon request.

To obtain information and/or data, please forward your request to:

The Director
National Geodetic Information Center, OA/C18
National Geodetic Survey
National Ocean Survey, NOAA
Rockville, Maryland 20852.

Telephone: (301) 443–8631

NOAA FORM 29–3 (8–81)

Article No. 26

Interim Status Report

by John G. Gergen

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Twenty-five articles describing the various aspects of the new adjustment of the North American Datum (NAD) have been published since the series began in 1975. The present article will present an interim report on the status of the project and will temporarily conclude this series of articles, since most of the important topics have already been discussed.

The NAD project began July 1, 1974 (Bossler 1975) and was originally scheduled to be completed by 1983. Difficulties with the procurement and operation of a new computer postponed the anticipated completion date by 2 years, to 1985. These delays have been detrimental to the project as well as to the surveying community, but it is believed that no additional postponements will be required.

Accomplishments

The following activities have been successfully completed:

- *Satellite Doppler Positioning* (Hothem 1977).
- *The U.S. Transcontinental Traverse* (TCT). The TCT represents the high-precision framework which will contribute to improved accuracy of adjusted positions throughout the U.S. horizontal control network. Field work was completed in 1978.
- *Data Base Management System* (Alger 1976).
- *Horizontal Field Work.* A total of 22 individual field projects have been executed in support of the new adjustment. Most projects were designed to strengthen the network and to fill some voids. The task was completed during 1981.
- *Block Validation and Helmert Blocking Tests* (Timmerman 1978).

Current Activities

The following projects which are in progress have firm completion dates:

Network Validation (Young 1976). This activity will conclude June 1982. The observable values in more than 5,000 individual field projects will be ready in machine-readable format, awaiting validation.

Software Development. A significant number of computer programs and systems are being developed. Many similar programs have already been written, but computer programs dealing with block validation and Helmert blocking represent the last two major systems needed by the project. This task is highly sensitive to the computer environment, i.e., the operating system, the languages, and the management of the computer center. Changes in these elements of the environment could have a negative effect on the progress of the entire project because most operations are highly dependent on the computer.

Mathematical Modeling. The mathematical model for the new adjustment of the NAD is a height-controlled, three-dimensional model (Vincenty 1980) completed in February 1981.

Predictions of the Deflection of the Vertical. All theodolite-occupied horizontal network stations require a predicted value of the deflection of the vertical (Schwarz 1979). A total of 100,290 sets of deflections of the vertical in the eastern section of the country has been predicted and subsequently loaded into the NGS data base. In the middle region, 37,826 sets of deflections of the vertical have been predicted and are awaiting entry into the data base. This activity is scheduled for completion in spring 1982.

Mark Maintenance. The mark maintenance activity for the NAD project represents the computation, conversion to machine-readable format, validation, verification, and adjustment of more than 15,000 individual mark maintenance projects. These projects are composed of the observations that were made for the recovery, replacement, and maintenance of horizontal control points in the national network. To date, a total of 10,764 projects has been placed in machine-readable format. There are 941 projects backlogged and 4,152 archival projects remaining to be processed. This activity will terminate June 1982.

Station Description Processing. Station description processing represents a significant activity. The objective is to load all descriptions in computer-readable format into the NGS data base for subsequent use during the project phase as well as for the publication phase. Most descriptions have been keyed from original records with subsequent storage on magnetic tape. Descriptions for most of the 250,000 horizontal stations have been processed since 1975. The station descriptions play an important role in the NAD project. Actual observations of horizontal directions and distances to the azimuth mark, and the two reference marks are highlighted in the box score of the description. It is important to validate all descriptions by checking the data against the actual observations; otherwise undetected errors may contaminate the descriptions and cause confusion to the practicing surveyor. This activity will continue for another 3 years. To date, only 74,616 descriptions have been loaded into the NGS data base.

Future Activities

Block Validation/Data Entry. Block validation represents the next major activity of this project. It consists of the systematic analysis of the U.S. horizontal network partitioned into more than 800 blocks, with an average of 300 stations per block. Observations in each block are validated and loaded into the NGS data base. This activity will begin July 1982 and conclude after 2 years, in the summer of 1984 (Isner 1977).

Helmert Blocking. Helmert blocking is the adjustment method used for the simultaneous adjustment of horizontal observations into an extremely large system of equations, 500,000 equations in as many unknowns if only stations' unknowns are considered (Hanson 1976; Isner 1981). This activity is scheduled in the future. It will start when a significant portion of the horizontal network has been successfully block-validated and will end when all horizontal stations in the NGS data base receive updated NAD 1983 coordinates.

Conclusions

The new adjustment of the North American Datum has been in progress for more than 7 years. Two major achievements are noteworthy: The NGS data base is a reality, and observations in about 5,000 horizontal projects have been validated and placed in machine-readable format. A 2-year setback occurred as a result of switching from one computer system to another.

The next 4 years, however, will prove that the project will be successful and that the new datum will provide the basis for future surveying activities. Even new satellite techniques, such as the Global Positioning System, would not be able to provide centimeter accuracy with respect to the national Geodetic Reference System in the absence of NAD 1983.

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