GEODETIC SURVEYING 1940 - 1990

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ABSTRACT

A whimsical, yet serious look at the events, technology advances and people of the past 50 years in geodetic surveying as seen through the eyes of one who traveled the road, all the way. The period is divided into three segments: Dawn of a New Era 1940 - 1950; Break with the Past 1950 - 1970, and New Age of Geodesy Begins 1970 - 1990. Each contains synopses of major happenings, anecdotes of the time and names of some of the people directly involved in the events. (C&GS) and (NOAA) following names indicate the persons were members of the commission officer corps.

DAWN OF A NEW ERA 1940 - 1950

The most progressive and productive era in American geodesy began innocuously enough, continuing much as it had in the 1930's and earlier decades. Coast and Geodetic Survey (C&GS) triangulation and leveling parties roamed the land establishing geodetic control, while a small office force processed the data for publication. This is how it had been for more than 100 years. There would be many changes in the next five decades.

Full Time Field Parties

Not surprisingly, field parties were to see the first of the changes. In the past, most personnel were hired for the length of the project and once the job was finished they were paid off and advised where and when another project was to begin. It was up to each to travel to the new location at their own expense. This practice changed in the 1930's and field parties became more permanent units, working the cooler climes in summer and the southern states in winter.

These arrangements made it conducive for party members to bring their families with them, living in privately owned house trailers in a self contained environment, usually in town parks, fairgrounds and the like. The all male tent encampments of the past, with their mess facilities, which contributed so much to the legends of field life disappeared, except for some mountain work and Alaska assignments. Field parties operated in this fashion for about 30 years before economic and other conditions made it impractical to continue that way of life.

First Computers Draw C&GS Interest

Events occurring at Iowa State University, Ames, IA, in the late 1930's and the University of Pennsylvania in the early 1940s would effect nearly everyone in the world in the ensuing decades. These events led to the construction of the first automatic electronic digital computer (EDC), the Atanasoff-Berry Computer (ABC) by John V. Atanasoff and Clifford Berry in 1942.

In 1946, J. Presper Eckert and John W. Mauchly under U.S. Army sponsorship, developed the mammoth Electronic Numerical Integrator and Computer (ENIAC) at the University of Pennsylvania. From this and other beginning efforts, John von Neumann developed the storedprogram EDC in the 1950's, the forerunner of present day equipment. The C&GS with its ever increasing volume of computations had a standing interest in anything new that might ease the burden and the developments didn't go unnoticed. Accordingly, early in 1942, Lansing G. Simmons, Chief, Philadelphia Computing Office made a visit to the University of Pennsylvania and found that the machine was still in a primitive stage and could not, for example, multiply positive and negative numbers and sum the results, an integral part of the adjustment process and geodetic computations in general. Nonetheless, he and others in the Geodesy Division were convinced that such machines would be the wave of the future, yet recognized it would be a decade or more before they would become available. In the interim period, high speed automatic computers were employed to ease the work load.

ADPs Used For Least-Squares Adjustment

In 1946, Charles A. Whitten made the first least-squares adjustment of triangulation using Bureau of the Census automatic, high-speed data processors. These International Business Machines (IBM) processors utilized punch cards in the calculations. The earlier computer developments had no direct bearing on this geodetic computation breakthrough, nevertheless the fact that the technology was on the horizon, was a contributing factor.

In 1948, the C&GS installed similar automatic computers (ADPs) and began the process of adapting them to geodetic computations. The ADPs were first employed to form and solve normal equations by the Doolittle method, up to and including the computation of the residuals stage. It wasn't that they could do the job faster, but more importantly that they could be run 24 hours a day, at a modest additional cost.

ADPs could solve about 15 equations in each 8 hour shift, and that was the solution rate most mathematicians (later changed to geodesist), in the Triangulation Branch, achieved in the same period. However, a few in the Branch developed superior speed and accuracy in operating rotary calculators, using a feel and sound system, rarely, if ever, viewing the keyboard or dials before completing a series of multiplications. This small group averaged 20 or more equations solved per day.

The end was drawing near for mechanical calculators, albeit it would be 20 years or more, before they were gone from most desks. More important to many involved in solving large sets of normal equations on such machines, was the fact that the drudgery of that job would soon be just a memory.

World War II Intervenes

During World War II, regular geodetic activities were suspended for the most part and much of the effort was directed to carrying out needed surveys at defense facilities in the U.S. and Caribbean area. Field parties operated at reduced strength or were disbanded and the office staff also was reduced as members of both groups entered the military. The major field work, accomplished in this period, was measuring an arc of first-order triangulation from Skagway in southeast Alaska, over White Pass to Whitehorse in the Yukon Territory of Canada, then following the Alcan Highway road builders north westward to Fairbanks, a distance of about 575 miles.

Alaska Surveys Accelerated

At the end of the war, with the connection to the lower 48 triangulation observed, plans were made to complete the primary horizontal control in Alaska and to tie the several local astronomic datums to the North American datum of 1927 (NAD27). This was a wise decision, considering that the Cold War got colder and oil was found on the North Slope shortly thereafter.

Several parties were in the field each working season and most of the work was done by 1956. Despite the hardships and danger, Alaska was considered a plum assignment and the per diem was higher too. The versatility of Bilby towers and the ingenuity of the men who built them was demonstrated time and again in Alaska.

Assistance to National Topographic Mapping Program

The last of the great arcs had been observed in the early 1930's, from Providence, RI to Key West, FL, following the Atlantic coast, a distance of about 1,600 miles. During the big push to complete the first-order network in that decade, which was funded by civil works programs, most were arc surveys. However, late in the decade the program to begin filling in the areas between the arcs was instituted. The program continued in the pre-and post-war years and into the following decades.

Much of the work was done in support of the U.S. Geological Survey's (USGS) nationwide topographic mapping program, involving control for a few quads here and a few quads there. This piecemeal approach was dictated by funding and other requirements. There was one exception, the USGS reached an agreement with the Commonwealth of Kentucky to accelerate the program there. To support that goal, the triangulation was completed, but for two small areas, by about 1950.

Although the area work was classified as second-order (the then 1:10,000 standard), the observations were made to first-order specifications, with minor exceptions. New standards and specifications were drawn up in 1957, which took these exceptions into account, so that all area nets could be classified to the same order of accuracy.

Computing Offices and SPCS

Computing offices were setup in New York City and Philadelphia to aid in adjusting the numerous new surveys made in the 1930's. Among the assignments, was the conversion of the published stations' latitudes and longitudes to plane coordinates on the recently created State Plane Coordinate System(SPCS). Early on, it was necessary to compute the required tables, as well.

These field offices were sponsored by the C&GS and funded by various civil works agencies. The NY Computing Office was in existence between 1932 - 1964 and the Philadelphia Office from 1940 - 1943. Both offices were placed under the Civil Service system about 1942. And, both contributed significantly to reducing the large backlog of work.

Calculating SPC's was a huge task, even after tables had been prepared. Originally both systems, Lambert and transverse Mercator, involved a combination of logarithms and natural functions and each computation was made in duplicate as a check. Tables for inverse computations were not available until the late 1940's. An addition check was made by computing selected grid distances between all points, converting these distances to geodetic values via scale factors and comparing them with the published results.

Even at the beginning, Lambert plane coordinates could be computed using natural functions, provided a 10-bank calculator was available, and few were in the 1930's and early 1940's. In the late 1930's Lansing G. Simmons, then in charge of the Georgia Geodetic Survey, developed tables based on empirical formulas to compute transverse Mercator coordinates using natural functions. The computation time was cut in half.

Use of Logarithms Near End

Many geodetic computations were made using logarithms, including the preparation of side and length equations, computation of triangle sides and geographic positions. The latter was a formidable chore, requiring 135 entries for longer lines. It was once estimated that the computation used up one mile of lead pencil. Others thought 0.5 mile was closer to the truth.

In 1941 Lansing G. Simmons, then in charge of the Philadelphia Computing Office, conceived position computation formulas, based in theory on the transverse Mercator projection, that was amenable to natural functions. Tables were prepared covering only the conterminous States (latitudes 24-50) and were in feet, with the idea that some surveyors and engineers would use geographic coordinates. It didn't happen.

And in 1944 tables were prepared in meters, extending from the equator to 75. In conjunction with the conversion, natural function tables for sines and cosines, at 1" intervals, were computed in the same office. The resulting Special Publication (No 231) soon became a best seller.

UTM Grid Developed

The Universal Transverse Mercator (UTM) grid, a world wide plane coordinate system was developed in the 1940's by the Corps of Engineers, U.S. Army, following the recommendations of Oscar S. Adams of the C&GS Geodesy Division. The grid consists of bands, 6 of longitude wide, and a maximum scale reduction of 1:2,500. Original tables (for the Clarke spheroid of 1866) were computed by a Civil Works project, in NYC, sponsored by the U.S. Lake Survey (USLS) during the early 40's. The USLS unit evolved into the Geodetic Division of the Army Map Service (AMS) about 1943. Later, tables were computed for other ellipsoids then in use. Floyd W. Hough, David Mills, Homer Fuller and Frank L. Culley were directly associated with the grid's development.

World War II Technology Advances Surveying

Technology developed during World War II began almost immediately to find places in surveying. Shoran, a special type of radar, was used to control hydrographic surveys in 1945. In 1946, Carl I. Aslakson (C&GS) examined its possible use in locating islands, atolls and the like, that were beyond visual means to geodetic accuracy. In 1951 the method was employed, with the longer range C&GS developed Electronic Position Indicator (EPI), to position 4 islands off Alaska in the Bering Sea.

In the early 1950's, the U.S. Air Force measured a Shoran trilateration net between Florida and Puerto Rico, continuing on to Trinidad and South America. A similar net connecting North America and Europe via Greenland, Iceland, Scotland and Norway was observed between 1953-1956 by the same organization.

In 1948 a novel survey procedure, flare triangulation, was used to connect the Florida mainland with the Bahamas. Flare triangulation involves simultaneous observations from at least 3 ground stations, on each land form, to a flare dropped at a prescribed location by a high flying aircraft. It was first used in 1945 to connect the triangulation of Denmark and Norway across the 90 mile span of the Skagerrak. While the experiment was viewed as a success there were too many problems, including the need for

near perfect weather conditions, for the method to be generally accepted.

Birth of EDMI

Erik Bergstrand's experiments, in Sweden, to employ light to measure distances came to fruition about 1948. This event was to have the same dramatic impact on geodetic surveying as did Jesse Ramsden's direction theodolite, reading to 1", in 1787. This instrument, named the Geodimeter, would reduce the time required to measure base lines from weeks to hours, without any reduction in the accuracy of the line. Furthermore, it permitted the measurement of regular length triangulation lines, doing away with the costly and accuracy lessening expansion nets.

A very eventful decade thus ended, holding great promises for the future.

BREAK WITH THE PAST 1950 - 1970

High Water Mark

The golden age of geodetic field operations in the U.S. began shortly after the war ended in 1945 and reached its zenith in the late 1960's. It began to fade in the early 1970's as governmental reorganizations and other factors, including economic conditions, directed funding priorities elsewhere. Despite these annoyances, even a name change, after more than 160 years the quality of the work was not effected. If anything it became better, albeit the productive rate was reduced.

For about 20 years, numerous parties were in the field carrying out mostly triangulation and leveling with smaller units doing triangulation reconnaissance, astronomic and gravity work. Sub units were assigned to various space and DoD facilities including Cape Canaveral, Vandenberg AFB, Pt. Mugu and White Sands.

The optimum steel tower party had 3 observing units and about 40 personnel, similar mountain parties about 30 people.

Wild T-3's Replaces Parkhursts

Wild T-3 theodolites replaced the Parkhurst, which had been in service for about 25 years, in 1952. Early fears that these small optical reading theodolites were unstable proved unfounded. Some observers found the T-3's stubby gun-sight pointers inadequate for night work and to resolve the problem taped beer can/bottle openers to the top and bottom of the telescopes. Fortunately, this piece of equipment was never in short supply on parties. Later illuminated finders, similar to those found on Parkhursts, were added.

Trivia details aside, economic benefits were accrued by replacing Parkhursts with T-3's. For the most efficient operation the Parkhurst required a 3 person observing unit, an observer, recorder and lightkeeper, who also read the second (B) micrometer. For T-3's the observer makes all the readings and on many occasions the lightkeeper was no longer needed, leaving the slots open for forming more observing units or showing additional lights.

Observation Equations Replace Condition Equations

After the purchase of automatic computing machines in 1948, several test adjustments were made under the overall direction of Charles A. Whitten, Chief, Triangulation Branch, to evaluate the method of observation equations (a k a method of variation of coordinates), both on the ellipsoid and the plane. By 1953, most large and many smaller networks were being adjusted using observation equations and few people had any doubt that the long reign of condition equations was about over.

It was obvious from the beginning that the method lent itself extremely well to automatic computers because the formation of the equations follow identical routines for each specific type of observation, i.e. direction/angle, distance and azimuth. There is no need to study the network to determine the number and kind of condition equations, nor to form them, difficult tasks at anytime. Observation equations require only the identification of the observations and assumed positions be computer recognizable, and similarly for the fixed positions, weights and any conditions placed on the observations.

Until late in the 1960's, it also was necessary to select the normal equations' solution order to minimize the computer space used. After 1970 this was done internally.

About 1957, with the purchase of an IBM 650 electronic computer the method of observation equations officially replaced the method of condition equations, which had been employed for more than 100 years, although the method would continue in use for another 10 years or so. By then, retirement and other forms of attrition had decimated the ranks of those who fully understood condition equations. And, the new generation of geodesists had, at best, only a superficial interest in the method.

In the same time frame, the Cholesky method for solving normal equations was introduced, its fewer steps making it ideal for use with computers. It had not been employed much previously because the fewer steps required didn't translate into significant savings in time and effort for hand computations when compared with the Gauss-Doolittle procedure used since 1878. Furthermore, Cholesky involved square roots that were not easily attained with mechanical calculators then employed. Gauss-Doolittle continued to be used for hand computations and remains a viable method for such calculations.

Computer capacity was limited and only the primary scheme was adjusted simultaneously. Supplemental stations, many positioned by single closed triangles, intersection points and other small jobs were often adjusted by hand, using condition equations.

About 1962, an IBM 1620 electronic computer, with a larger capacity and faster became the work horse of the bureau for a decade before being replaced by a still larger and faster computer. As computer capacity improved, the supplemental and intersection points were adjusted in separate computations and eventually entire networks were adjusted in single weighted computations.

Modern Adjustment Theory Becomes Rule

Early in the change over period, base lines and Laplace azimuths were held fixed in accordance with long practice and considered opinion that these observations were far more accurate than the angle measurements. However, this rationale changed within a few years, as modern adjustment theory that all observations should receive corrections was accepted. By 1965, accuracy estimates were routinely computed as well. Neither practice was really meaningful, because most of the adjustments of the time were badly constrained. From the beginning, accuracy estimates were expressed in terms of probable error and the practice continued until about 1970 when the standard error concept, conforming to modern error theory was adopted.

Data sheets containing all information, other than descriptions, were computer generated by the early 1970's.

Charles A. Whitten - Geodesist

Charles A. Whitten, far more than anyone, brought geodetic computations into the computer age. His successes with punched card computations (1948-57) provided the catalyst and know how needed to adapt the early electronic computers for similar computations. His leadership and interests in adapting the ever improving computers to geodetic needs didn't end with his retirement in 1972. He was often consulted for his expertise in a wide range of geodetic matters as well, continuing to make significant contributions for the next 20 years.

Whitten was a man of many talents, a superb all around geodesist who for more than 40 years served in a variety of positions including Chief of an astronomic party, Chief, Triangulation Branch and Chief Geodesist. A strong advocate for utilizing geodetic surveys to measure crustal motion, Whitten published numerous papers on the results and was convinced such data would one day contribute to the prediction of seismic events.

He was recognized internationally for his work in adjusting the triangulation of western Europe, the basis for the European Datum 1950 and was President, International Association of Geodesy (IAG) 1960-63. Charles A. Whitten died in 1994, at age 84.

Early Geodimeters

The C&GS obtained its first electronic distance measuring instrument (EDMI) a Model 1 Geodimeter in 1953, and the second a Model 2 Geodimeter in 1956. In the period 1953 - 1958, 84 triangulation lines were measured, the first between stations KILIAN and THERESA in eastern Wisconsin, a distance of about 2.25 miles. Four previously taped base lines were included in the total. Each line was observed on at least two separate nights, except for 4 lines in Arizona where only one measurement was made. A measurement consisted of 6 observations, spread over 75 - 90 minutes. The longest line observed was 26 miles, the shortest 0.7 mile and the average 10 miles. All new lines were satisfactorily included in the adjustments of the triangulation.

Both models weighted in excess of 300 lbs. and while good results were obtained from 12 ft. wooden towers, those from a 103 ft. Bilby tower were not, primarily because of stability problems. The problem was resolved in short order. C&GS field personnel were highly skilled in adapting equipment to fit any need, and this situation was no exception.

As a result of these tests, a first-order base line was specified as resulting from 12 complete observations, 6 on one night and 6 on the second.

The most obvious conclusion drawn was the 140 year period of measuring base lines with various mechanical apparatus had ended. Accordingly, the last regular taped base line was measured near Salmon, ID in 1958. Base lines specifically measured to test EDMI were taped at Beltsille, MD in 1964 and near Culpeper, VA (MITCHELL Base) in 1965, with a highly accurate remeasurement in 1967. The first was slightly more than a mile in length, the second about 5.6 miles.

Lasers Give Longer Range

New model Geodimeters were considerably lighter than early versions and weight was no longer a bother, however longer range, especially in daylight and haze was desired. To achieve this, George B. Lesley modified a Model 4D Geodimeter with a 2 milliwatt laser as the light source in 1965. Tests showed conclusively that the desired results were obtained. Ten mile lines were easily measured in bright daylight and at night, a stronger light return at all times. Furthermore, successful measurements under adverse weather conditions were the rule. On the basis of these tests, AGA (Geodimeter Co.) was contracted to convert about 15 Model 4D Geodimeters, then in use in the U.S., to laser instruments.

In the 1970's, Lesley replaced the 2 milliwatt laser in an instrument with a 10 milliwatt one. This extensively modified Model 4D, known as Big Red, routinely measured distances in excess of 50 miles in daylight. AGA and other firms produced laser instruments in the late 1960's.

Tellurometers and Other Microwaves

EDMI using microwave as a measuring source appeared on the scene about 1957. Tellurometer was the first, developed by T.L. Wadley of the South African Research Council. They were lightweight, operated in daylight, had long range capability and less expensive than electro-optical instruments, good features that attracted many surveyors. However, the observations were seriously effected by humidity, especially on longer lines and by a condition known as ground swing. The latter could be corrected by taking certain steps, but was not always recognized.

During the interstate highway program many surveys, including most by the C&GS, were microwave measured traverses and could only be classified as second-order class II (1:20,000) for this reason. Had electro-optical instruments been employed, these surveys would have rated at the very least, the next higher accuracy class.

First 1:1,000,000 Survey

As space and missile programs began expanding, it was recognized that a super accurate nationwide horizontal network was needed. It was readily apparent, that the recently invented EDMI would play an important role and that the simplest solution would be to weave an electro-optical traverse through the existing network, utilizing the original monuments wherever possible. Lansing G. Simmons, the Chief Geodesist, devised a scheme that amounted to parallel traverses, by using diamond shaped figures created by setting an auxiliary point, about 25 m. distant from every other station and connected to it. All observations were to be made at least 25 ft. above the ground, on two nights, including astronomic azimuths at the terminals of the diamond figures. Astronomic positions were observed by a special unit.

When longer range EDMI became available, sliver triangles and even single line configurations were permitted, in some instances, under controlled circumstances. Early on, taking mid-point temperatures was required, using balloons to hoist thermistors to the line height. This requirement was dropped in the later stages, except in the mountains or on long lines. Airplanes carrying thermistors on their wings were used on a few occasions to fly such lines to obtain average temperatures.

The survey began in 1961, in Florida, completed in Michigan in 1976 and is known as the High-Precision Transcontinental Traverse (TCT). It has an accuracy of one part in a million or better, the most accurate survey ever made using conventional methods. About 2,750 stations were included in the 13,660 mile traverse that passed through 44 States. A section originally proposed from Maine to Michigan via Canada was abandoned because space and satellite technology gave good promise for even higher accuracy nets. Much of the funding was provided by DoD, in addition to assistance in measuring several legs.

Cooperative Surveys

About 1960, the C&GS began emphasizing cooperative arrangements for establishing control in urban and county areas, even statewide. Such undertakings were not new, dating back to 1903 - 1908, when Congress ordered a survey of greater New York City to the more recent (about 1950) East Bay Cities network.

From 1960 to 1980, about 50 such projects were observed. Many were truly cooperative, as local surveyors worked side by side with C&GS/NGS personnel in positioning points selected to control proposed local traverses.

Mark Preservation and State Advisors

From a modest beginning about 1950, the mark preservation program came to full bloom in the early 1970's, saving thousands of stations and bench marks along the way. Unfortunately, the work, skills and dedication of the mark dusters was not understood, nor appreciated in high places and they are no more. Their loss is everyone's loss, once a monument is gone, its gone forever.

State advisors appeared later in this time frame, as States began making geodetic quality surveys for highway and other purposes. Fortunately, the program continues and with that, the hope that a volunteer mark preservation plan will be developed. Where once instructing in geodetic surveying was the primary purpose, it now appears advising in cadastre matters is the principal function of the job.

First Worldwide Network

Between 1966 - 1973, a 45 station world-wide satellite triangulation network was observed under the technical supervision of the C&GS. The communist bloc countries did not participate causing a hole in the net to the north, and the lack of even the smallest island in the south Pacific Ocean created another.

Captain James Cook on his 18th century voyage to that region had reported a least depth, at an acceptable location, that could conceivably hold a platform; one thought being to sink an old ship as the base for the observations. The spot couldn't be found. Hellmet H. Schmid directed the overall operations and the project was managed by L. W. Swanson (C&GS. The latter was a complex and difficult job. The logistics involved in moving heavy equipment and personnel to so many out of the way places was a huge and complicated task. And, dealing with representatives of foreign countries, an entirely different and more delicate one. Funding for this multi-nation effort was provided primarily by DoD.

The basis for the net were directions, determined photogrammetically from photographic plates, showing the trace of a balloon satellite against a star background. The plates are the end product of simultaneous observations, obtained by very accurate ballistic cameras, from at least two stations.

The method provides geometry and orientation, but not scale, which was introduced by 7 long base lines measured in the U.S., Europe, Africa and Australia with the shortest being 743 miles and the longest 2,166 miles. Positional accuracies were on the order of 5 meters. A proposed North America densification net was dropped as more accurate and less expensive positioning systems became operational.

Measuring Crustal Motion

Geodetic surveys are excellent tools for measuring the amount of horizontal and vertical movement due to seismic and other events. These procedures were not employed much until the 1940's because of a lack of previous surveys, needed for comparison purposes, in many effected areas and cost.

Resurveys were made after the 1906 San Francisco earthquake and the primary arc from Lake Tahoe to San Francisco, then south to Santa Barbara Channel and east to the Imperial Valley was reobserved in 1922 - 1924, but little else was done, except for one short arc reobserved and some releveling in the 1930's. A plan was formulated in this decade however, to reobserve and relevel selected nets at specific intervals and to carry out resurveys, following major earthquakes, as soon as practical.

In the next 3 decades, a number of these nets and lines were observed as planned and several were reobserved as scheduled. One of the first resurveys, made following an earthquake, was the 1935 Imperial Valley, CA triangulation in 1941 after a major seismic event in 1940. Other resurveys included, the Dixie Valley triangulation, near Fallon, NV, following a large earthquake in 1954 and much of the existing work within a 150 mile radius of Anchorage, AK after the Prince William Sound seismic event in 1964. To measure the slippage along the San Andreas Fault, 30 small nets straddling the fault, with sides 200 - 600 m. in length, containing 6 - 8 stations and independently scaled and oriented were established between 1964 - 1967, in cooperation with the California Department of Water Resources. All but one were resurveyed at least once before 1970.

Charles A. Whitten and Buford K. Meade wrote numerous scientific papers dealing with the results of the surveys. With the transfer of seismology functions to the USGS about 1970, in-house interest began to wane, coming almost to a stop in the 1980's.

Special Purpose Surveys

Special purpose surveys made in the 1940 - 1980 period included those for:

David Taylor Model Basin, MD.

Straits of Mackinac Bridge, MI.

Triangulation and leveling networks for the Blue Nile River Basin, Ethiopia.

Several linear and circular accelerators in NY and CA. Astronomic observations at Thor missile sites in England, at the time of the Cuban crisis.

Arizona-California boundary, where the actual boundary, the center of the Colorado River, is defined by positions determined photogrammetically from shore line control.

Super-precise alignment and measurement of the Holloman AFB rocket sled track.

Resurveys of the north-south Mason-Dixon line between Delaware and Maryland and the east-west line between the two states, originally surveyed by colonial surveyors.

Extension of Louisiana triangulation to locate oil drilling rig platforms, 50 miles in the Gulf of Mexico utilizing Bilby towers anchored on the platforms.

Astronomic positions observed at about 30km (18 mi.) intervals to determine the astro-geodetic profile along the 35th parallel.

Position and azimuth determinations at Polaris submarine servicing facilities.

Surveys to delineate the U.S.-Mexico boundary at the mouth of the Rio Grande River and its extension to the Pacific cean, south of San Diego.

Astro-geodetic deflections for use in correcting the observed angles included in NAD83, observed at about 100 stations, mostly base line points involved with steep lines. Observations to upgrade the national net on Fishers Island, NY for U.S. Navy Underwater Sound Laboratory.

Astronomic positions to verify the California-Nevada boundary at Lake Tahoe.

Surveys at Goldstone (near Barstow, CA) and MacDonald (Davis Mtns.,TX) observatories, the latter to study any motion relative to the LURE observatory on Mt. Haleakala, Maui, HI. Nuclear test sites.

Subsidence studies at the White House.

Locations of numerous missile sites.

Not All Plane Surveying

In 1965, a Tellurometer traverse was measured by a U.S.- Canadian field party connecting the Alcan Highway triangulation and the coastal surveys at Yakutat Bay, AK, tieing in the recently named Mt. Kennedy. While the connection is of minor importance, the experience of the observing unit atop Mt. Kennedy is an outstanding example of the adage, when things go wrong, they go very wrong. Several days after setting up a camp in a saddle just below the summit, an unexpected storm struck destroying their tents and protective snow block wall. This major disaster forced the men to spend 14 hours to dig a 9 ft. by 10 ft. and 5 ft. high ice cave, where they lived for 8 days with 100 MPH winds and - 40F temperatures outside. After a short break, another storm struck and it was 5 more days in the cave. More problems were still to come. A helicopter, sent to bring the unit back became disabled, requiring a larger Canadian Air Force copter to bring the men and disabled machine to Whitehorse. A few days later, the observer Paul H. Swift, returned with two new assistants and completed the observations on the first day. The story doesn't end there.

Another storm hit and they had to spend 3 days in the cave, making it 16 days of cave time for Swift. To him it was just another C&GS work assignment some being good and some, being not as good. This one fell in the not as good category.

New Standards of Accuracy

New standards of accuracy and specifications were issued in 1957, replacing those used since 1933. For the first time, the classic first- and second- order standards for triangulation were subdivided into classes, recognizing the need for higher accuracy surveys, as well as to establish a national standard for area triangulation.

Other Significant Contributors

Other organizations made significant contributions to the national networks during the period. Among the most notable are: The USGS, a number of State DOT's, especially California and Minnesota, and the unique North Carolina Geodetic Survey organized in the early 1960's. It has established thousands of points statewide in the interim. Another unique group exists within the Los Angeles County Engineer's Office, which routinely carries out first-order horizontal and vertical surveys. All other contributions were second-order. The South Carolina Geodetic Survey, last of several such county and state agencies to be formed, began operations in the late 1970's and continues today.

Geodetic Leveling

The vertical control network grew from 45,000 miles in 1929 to about 260,000 miles in 1940 and more than 420,000 miles by 1970 - - and with little fanfare. Geodetic leveling has none of the glamour or adventure, associated with triangulation, and receives little publicity about its operations. There are no high mountains to climb or tall towers to build, no 100 mile long sights, nor 15 mile base lines to measure, only endless hours walking along railroad tracks and roads day after day, making observations every 400 ft. Yet, the work gets done and to a high accuracy, as well. And, so it was for the period 1940 - 1970. About the only changes were the Fischer level, in use since 1899 and C&GS designed invar rods from 1916, both replaced by equipment of European design and manufacture, about 1967.

With the Fischer level retired, no longer could one view a C&GS levelman lift the Fischer tripod, instrument attached, kick the forward leg up and out, spread the others, then ride the apparatus into the ground, bring it to level and ready to observe, all in what seemed like one, single smooth motion. Modern levels can't be handled in that fashion.

Thus ended the last decade of the old era only we didn't know it at the time, nor just how good we had had it.

NEW AGE OF GEODESY BEGINS 1970 - 1990

NOAA Arrives

The period begins with the reorganization of ESSA, which included the C&GS, and was created in 1965 becoming NOAA. Among the changes, C&GS was renamed the National Ocean Survey (and renamed again later as the National Ocean Service)(NOS), bringing protests from many in the surveying profession, all to no avail. To some of us, it was not the best of times, yet even then, we found that the sun always rises. To wit, in the early 1990's, the name was restored to part of the old bureau. Then taken away again in 1995. The Geodesy Division became the National Geodetic Survey, alternating as a division or an office in the several reorganizations within NOS.

Cost-Cutting Measures Increased

With the reorganization pressure came to cut costs and as is the usual case, that meant field operations. As a starter, specifications for urban surveys were modified - - no savings were realized. Mixed mode surveys (mixture of triangulation, trilateration and traverse) had the best chance to save money and a number of projects were proposed and carried out. Several excellently designed truck mounted towers and masts had been built specifically for such work, but there were never enough of them available for efficient operations and little savings resulted. Motorized leveling techniques, developed in Sweden, were only moderately successful in the more congested U.S. and cost savings were small.

Devices for recording leveling observations and programmable desk top calculators contributed to more efficient and accurate field computations. Eventually, all field parties were equipped with computers and terminals tied to the office facilities. Computations became easier to make of course, but the cost savings, if any, are difficult to ascertain.

Applications of New Technology

The 1970's saw the introduction of several pieces of exotic instrumentation and in one case, precision application of older technology. About 1971 the first direct positioning, all weather system, using satellites became operational. Based on the Doppler principle, and using radio signals from the U.S. Navy TRANSIT satellites, the results were accurate to about one meter in each component. As a general rule, Doppler positions were spaced at about 200 km.(125 mi.) or more when used to control first-order networks. Although the instruments were lightweight and portable by 1977, they had little practical application.

Very Long Base Line Interferometry (VLBI) using extraterrestrial radio signal sources produces super accurate distances and azimuths over continental distances. Early observations were from fixed antennas, although some progress in making them portable was made later.

Inertial Positioning Systems' (IPS) all weather, day and night methodology came on the scene about 1978 and appeared to be the answer for densification work because of its capability to rapidly position points to an acceptable accuracy. Several federal agencies including the NOS/NGS utilized the systems for secondary surveys and a few cities in establishing local grids. The systems faded away by 1983 because of various factors, including high instrument cost.

High Precision Photogrammetry (HPP) was employed in 1978 to locate 346 section corners in Ada County, ID to second-order class II accuracy (1:20,000), in a short time frame and at a moderate cost - - then was not used again. One reason for the lack of interest might be that the only generally available report dealt largely with the photogrammetric reduction and adjustment phases of the project, and nothing about the relative ease of field operations.

GPS Operational

The most important development in the history of surveying occurred early in the 1980's when the NAVSTAR Global Positioning System (GPS) became operational. Surprisingly, few in the profession were aware it was about to happen. Tests made early in 1983 showed conclusively that the system employed in the differential mode (DGPS), routinely gave one part in a million accuracy between points spaced 1 to 25 miles apart.

With the announcement of these results, the geodetic world was turned topsy-turvy, theodolites, EDMI and Bilby towers became obsolete overnight, although the instruments would continue to be used in other surveys. As for Bilby towers, the last erected by the NGS was in September 1984 at a station appropriately named BILBY, near Hartford, CT.

Very early, there was no doubt that GPS would be the modus operandi for establishing new horizontal networks, to upgrade existing nets, and one day establish vertical control nets as well. To that end, in October 1983, NGS completed the observations for the first regular GPS survey, an urban type network for Summit County, OH, and the second in December 1983, at Fort Stewart, GA. On the basis of early results, GPS in the kinematic mode shows great promise as the long sought after rapid positioning technique for densification nets. In another vernacular, GPS is the greatest invention since sliced bread.

Total Stations and CBLs

Beginning in the 1970's, a virtual plethora of short range EDMI, modern transits and theodolites and eventually the marriage of the two, the Total Station, were available. By the late 1980's, most surveyors were equipped with at least one of the new instruments. There was one problem, EDMI require periodic accuracy evaluations and verification of the instrument constant.

To assure that test facilities would be available, NGS initiated a cooperative program about 1973, to provide Calibration Base Lines (CBL's) at selected sites nationwide. L.S. Baker (NOAA), then Director of the Survey, and a man always looking for ways to benefit the profession was responsible for its creation.

The first was measured in October 1973 at Liverpool, NY, using standard first-order base line taping procedures, as were 3 other CBL's prior to 1975. Beginning in 1974, a new procedure combining precise taping and high accuracy EDMI observations was adopted and continues in use today. The method was proposed and developed by Raymond W. Tomlinson and employed by him for the first time in July 1974 on the Rockingham-Hamlet, NC CBL.

A standard CBL has monuments at 0m., 150m., 430m. and 1,400m. By 1990, more than 275 CBL's had been measured.

Standards of Accuracy Revised Once Again

Updated and revised standards of accuracy for geodetic control surveys were issued in 1974, replacing the 1957 version. Detailed specifications were published, for the first time, in 1975 and revised in 1980. Standards and specifications for trilateration based on 10 years of extensive field tests were provided, also for the first time.

In 1984, standards basically unchanged from the 1974 criteria and much less detailed specifications were issued, primarily to introduce different statistical philosophies than used heretofore. For some reason, trilateration was omitted. With GPS operational at the time, interest in such information was not very high.

More importantly, provisional standards and specifications for DGPS surveys were made available in 1988.

The Training Craze

Has anyone ever wondered where the present day workshop- seminar craze began ? The idea came up following a successful 1969 C&GS sponsored symposium dealing with automation of surveying equipment and data acquisition, reaching fruition in 1971.

The Surveying Instrumentation and Coordinate Computation (SICC) Workshop, the first such endeavor, was held at Madison, WI on February 8 - 10, 1971, sponsored by the University of Wisconsin Extension Service under the able direction of the late William R. Baker and NGS. NGS furnished 7 instructors and educational materials and manufacturers, the instruments. The cost was $60, which included lunches, coffee breaks and was limited to 72 attendees. SICC Workshops became affiliated with ACSM in 1972 and remain available today. More than 35 workshops were presented by 1990.

The Palmdale Bulge Controversy

One of the biggest geodetic controversies since the 18th century British-French debate, whether the earth's shape was prolate or oblate, erupted in the late 1970's over the Palmdale Bulge. A well publicized event, newspapers are always interested in geologic mysteries.

One group contented that the historic leveling and relevelings showed conclusively that the plateau centered near Palmdale, CA had uplifted 10 to 16 inches. Another group eventually counter claimed that the differences were due to instrument and systematic errors resulting from observing practices and atmospheric effects, especially refraction.

Field tests made in the 1980's, showed that the latter conclusions were correct. However, not every one was convinced that was the case and some hold to their original views even at this date.

Flaws Found in NAD 27

Ten years after the completion of NAD27 (about 1931), it was readily evident that the datum was seriously flawed because of too few base lines and Laplace azimuths overall and very large loops in the west, some being 1,000 miles or more in length. The eastern half had additional problems too, due to large junction figures which allowed, in some cases, too little triangulation to absorb position closures; by fixed points on the 98th Meridian arc adjusted in the western half and the need to readjust a large portion of the Great Lakes triangulation to fit one point to the International Boundary work. The expression throw it in the lake originated from this predicament. In any case, it didn't stay there.

NAD 83 and John D. Bossler

Little could be done, of course, until much more of the network was completed. About 30 years later that time seemed to have arrived. In-house discussions led by L.S. Baker (C&GS), Chief of the Geodesy Division and Charles A. Whitten, the Chief Geodesist began about 1968. A year or so later, meetings with the Canadians were held. The exchange of ideas with several interested parties was culminated with a 1971 report by a special committee of the National Academy of Science (NAS) endorsing the need for a new adjustment.

The official kickoff date was July 1, 1974, although some work was begun a year earlier. John D. Bossler(NOAA) was named NAD Project Manager and served until 1983, when he moved up, becoming Director, Charting and Geodetic Services (C&GS). Prior to that he was named Director, NGS in 1980 and following his retirement in 1986 he founded and presently (1994) is the Director, Center for Mapping at Ohio State University. Bossler's strong leadership in unison with excellent technical and scientific skills combined with his ability to deal with high level bureaucrats had much to do with the successful conclusion of the project, and with little change from the original plan. In the scheme of things government, this alone is a tremendous achievement.

NAD83 includes in addition to the entire U.S. network, the primary systems of Canada, Mexico, Central America and Greenland. The statistics are mind boggling. The U.S. net alone (approximate numbers) includes 5,000 projects, containing 259,000 points, involving 1,734,000 weighted observations, requiring the solution of 929,000 unknowns.

The parameters of the Geodetic Reference System 1980 (GRS 80) were adopted, replacing the Clarke spheroid of 1866, that had been used for more than 100 years. The datum is earth centered by the introduction of 655 Doppler positions as observations. Also included were 112 VLBI measurements.

Few computers available in 1974, if any, had the capability to handle this enormous amount of data. Fortunately, capacities were increased significantly in the next decade. All data, including descriptions of points are now in a computer data base. The project was completed on July 31, 1986 and cost 37 million dollars.

HARNs Upgrade NAD 83

A clamor arose, even before it was completed that NAD83 was not accurate enough to satisfy future needs. Some argued that its use was further limited because too many points were located on hilltops and other not easily accessible places.

The cause for the uproar was GPS had become operational earlier and was compounded by all the razzmatazz that followed about its accuracy and ease in making observations almost anywhere.

C&GS studied the problem and while not agreeing with all of the arguments, developed a plan to provide under cooperative arrangements GPS High Accuracy Reference Networks (HARN) on a state-by-state basis. The emphasis being on statewide nets. Depending on certain conditions, stations are spaced at 15 - 60 miles with an internal accuracy of about 1 ppm or better. The end result, a statewide, independent, upgraded NAD83 network. By the Fall of 1993, HARN's were in place, or will be shortly in 27 states, with points spaced at 60 miles or less. This piecemeal approach satisfies most users. However, sometime down the road, there will be a new adjustment of NAD. When, is another story.

Landmarks No Longer Positioned

Once GPS became the sole method for making horizontal geodetic surveys, landmark stations such as church spires, water tanks, radio masts and others, usually referred to as intersection points were no longer positioned. The points presently in the files were and are still used for local azimuth control, resections and even as position control, among other uses, will physically disappear with time, of course. By then we can assume that surveying will be totally dominated by satellite technology and their loss will cause little concern.

CORS Program Begun

About 1992, NGS formulated a plan to establish a network of Continuous Operating Reference Stations (CORS) through out the country with the primary purpose in support of marine and navigation systems. However, CORS has the potential for accurate 3-D positioning, to the datum, within a 20 - 30 mile radius of the sites, and a promise of higher accuracies over longer ranges later. By early 1996, more than 50 CORS were in place, positioned to accuracies of 3 cm horizontal and 5 cm vertical, with the ultimate accuracy goal of 3 mm, in all dimensions, sometime in the future.There is little reason to doubt now that the age of single person survey parties is upon us !

NAVD 86

In the 1970's, NGS contracted out geodetic surveys for the first time, when Vernon F. Meyer and Associates, Sulphur, LA successfully undertook first-order leveling surveys.

By 1980, the National Geodetic Vertical Datum of 1929 (NGVD29), known prior to 1973 as the Sea Level Datum of 1929 (SLD29), had grown to 435,000 miles of first- and second-order leveling. As with NAD27, fitting new leveling to the old was a continuing problem.

Accordingly, in 1978, a committee of NAS endorsed a 1975 NGS position paper that defined the necessary steps to upgrade and make a new adjustment of the network. Technical exchanges were held with the Geodetic Survey of Canada and later with representatives of Mexico and Central America.

One of the decisions reached was to include Canadian and Mexican leveling in the adjustment. To reflect this situation, the name was changed to the North American Vertical Datum of 1988 (NAVD88). It also replaces the International Great Lakes Datum of 1985 (IGLD85).

Leveling field work was accelerated beginning in 1977 and was completed in the late 1980's, including more than 50,000 miles of first- order relevelings. David B. Zilkoski was named Project Manager NAVD in 1986 and ably directed the investigations, evaluations and the new adjustment completed in June 1991, with the results published later in the year.

The datum is defined by the IGLD85 elevation for the primary tidal bench mark at Father Point/Rimouski, Quebec, Canada at the mouth of the St. Lawrence River. The adjustment is a minimum constraint computation involving 875,000 unknowns and provides the best possible differences of elevation available from the observations. At the same time, it minimizes the impact on the USGS mapping projects.

About 20%, or 90,000 miles of old leveling is in crustal motion areas or did not fit the new observations and was not included. These data, identified as POSTED, will be adjusted and the results published in the near future.

One last point. It is very likely as we enter the last decade of the 20th century, that levels and rods will fall victim to GPS, as did theodolites, EDMI and Bilby towers.

Personalities

History records events and the names of the people making major contributions to them. To that end, some of the people so involved in the 1940-90 period are cited in the text. However, there are others, not directly associated with these events, who played equally significant roles and they, too deserve recognition. For practical reasons only a few can be included in the following sketches. All were affiliated with C&GS - NGS unless noted otherwise:

In the early 1930's, Buford K. Meade changed the way least-squares adjustments had been carried out for about 90 years by accumulating the multiplications when reducing normal equations on desk top calculators (then coming into general use), replacing the practice of tabulating each calculation, and thereby halving the time required. i.e. The average time previously was about 1-hour per equation or 10 to 12 8-hour days to solve 100 equations.

During his long career he developed several unique and innovative adjustment procedures for traverses and special surveys, analyzed numerous crustal motion surveys and prepared reports explaining the results, carried out a continuous evaluation of the TCT during the 15 years it was in progress that included investigations of the EDM measurements, leading to more accurate distance observations and examinations of the Doppler positions associated with the survey.

Meade was Chief, Triangulation Branch / Horizontal Network Division from 1963-74, when he was appointed Chief, Control Networks Division, the name assigned the Chief Geodesist's position in the 1970's.

James B. Small and Norman F. Braaten directed the Leveling Branch for some 20 years from about 1955 during a period of change, instrumentally and technically that rejuvenated the leveling program. Had either been on staff at the beginning of the Palmdale Bulge controversy, their long leveling experience and vast knowledge of the network could have put an end to the argument in short order.

Charles N. Claire worked with Oscar S. Adams in developing the SPCS and continued a career long effort to improve and simplify its use through publications and easy to use projection tables. He was experienced in a wide range of geodetic activities and in some was recognized as the leading expert.

Joseph L. Stearn introduced matrix algebra and modern statistical error theory, as applied to geodetic computations to C&GS personnel beginning in 1949 via in-house seminars. He later expanded the material to course length and taught the subject at local evening schools and universities attended by many in the profession from several agencies.

Earl S. Belote spent most of his 33 year career in the New York Computing Office where in 1946 he devised a traverse adjustment method that produced scalers to the distances in accordance with the direction of the line. A similar procedure was introduced in NAD 83 to determine group scalers according to instrument and organization. About 1948, when it became obvious that trilateration would become a practical method for establishing control, he conceived condition equations for its adjustment. Belote also developed an adjustment procedure on the plane using precise transverse Mercator grids and observation equations that produced results identical to a computation on the ellipsoid. Several large networks were adjusted by this method between 1949-57.

Donald A. Rice played a leading role in the gravity program where, in or shortly before his tenure as Chief, Gravity and Astronomy Branch, gravity meters replaced pendulum apparatus, Wild T-4 universal theodolites replaced Bamberg broken telescopes for astronomic work and there was a huge increase in the number of astronomic position and azimuth determinations (more in 20 years, than in the previous 100 years) brought on by geoid profile studies and TCT needs. Shortly before his retirement, Satellite was added to the branch name to reflect that Doppler positioning was viable alternative to standard geodetic procedures.

T. Vincenty (USAF) and (NGS), known to one and all as TV, contributed numerous articles over about 25 years, dealing with a variety of geodetic matters, most presented in a succinct fashion. In some, he chided the geodetic community for not doing more to obtain results closer to the theoretical best values, and in a sense was the conscience of geodesy during that time.

Vincenty's work in adapting 3-dimensional adjustment techniques to NAD 83, made for the least restricted computation and is credited, by some, for reducing the number of iterations required for convergence. Approaching retirement, he updated and reformatted the SPCS projection equations for NAD83.

Irene Fischer (AMS)/(DMA) was long recognized as the U.S. expert on datums, ellipsoids and the geoid despite the fact that few results of her efforts will ever come to light, because much of her work was done under military security rules. However, anyone who ever heard Mrs. Fischer discuss these elements, among the least understood of geodetic subjects, always came away with a clearer picture of them and convinced that she indeed knew her stuff.

Richard J. Anderle (Naval Surface Weapons Center) spent a large part of his career developing equipment to employ satellites for positioning purposes. First, the Doppler system which provided positions to an accuracy of ± 1-meter in each component and second, GPS where in the relative mode, accuracies of 0.1 ppm are possible. No one, as yet, has been identified as the father of GPS and its not suggested that Anderle was, however he was a member of the immediate family.

Well, that just about covers the 50 year period. Where do we go from here? We know for the next decade, GPS or GPS related technologies will dominate. After that it's anyone's guess - - a safe one though, is more of the same and at all levels of surveying.

POSTSCRIPT

On June 25, 1995, as a result of another governmental reorganization, the name Coast and Geodetic Survey ceased to exist. This the second time since 1970 that such a decision has been made; the name was revived in 1991. Whether the action is the final disposition of a proud and highly honored name remains to be seen. If indeed this is its fate, geodetic surveying in the U.S. and in fact, worldwide will have lost a distinct and continuous link to its earliest time, and a major player in its history. A sad commentary on the mode of the day, where apparently nothing from the past is considered worth saving.