GEODETIC OPERATIONS IN THE UNITED STATES AND IN OTHER AREAS THROUGH INTERNATIONAL COOPERATION

1957–1959

Publication 60–2

JOHN H. BRITTAIN

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

UNITED STATES DEPARTMENT OF COMMERCE

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January 1, 1957, to December 31, 1959

[Report to the International Association of Geodesy of the International Union of Geodesy and Geophysics, International Council of Scientific Unions]

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UNITED STATES

GOVERNMENT PRINTING OFFICE

WASHINGTON : 1960

PREFACE

This publication constitutes one of a series of triennial reports to the International Association of Geodesy on the geodetic activities of various agencies in the United States covering the period from January 1, 1957, through December 31, 1959. It will be distributed at the Twelfth General Assembly of the International Union of Geodesy and Geophysics to be held at Helsinki in July–August 1960. The material of this report has been arranged in five parts corresponding to the five Sections of the International Association of Geodesy. These parts will be separated and thus serve as individual reports of the five Sections and will be distributed at a later date by the Central Bureau of the International Association of Geodesy.

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GEODETIC OPERATIONS IN THE UNITED STATES AND IN OTHER AREAS THROUGH INTERNATIONAL COOPERATION, JANUARY 1, 1957, TO DECEMBER 31, 1959

By JOHN H. BRITTAIN, *Chief, Geodesy Division, U.S. Coast and Geodetic Survey*

TRIANGULATION

U.S. Coast and Geodetic Survey

Considerable progress was made during the 3-year period covered by this report on the extension and further development of the horizontal control network in the United States. The major part of the effort involved the breakdown of networks with additional arcs and the completion of area or fill nets within the basic framework.

The preliminary surveying and mapping needed for the construction of the Interstate Highway System have required the extension of geodetic surveys along the proposed routes of this highway system. Geodetic surveys that are marked with permanent monuments have been made along several thousand miles of these new superhighways in all parts of the United States.

The last 3 years have seen an increased use of electronic equipment for the measurement of lengths. Practically every triangulation party is equipped with a Tellurometer so that triangulation, trilateration, or traverse may be observed with the specifications of each individual project determining the type of survey equipment and techniques to be used. Geodimeter Models Nos. 2 and 4 also are used extensively. A geodimeter party has been in operation almost full time measuring first-order base lines in new nets as well as measuring primary lines of triangulation in older networks, in order to provide adequate length control for some possible future readjustment.

Every Federal Agency engaged in geodetic work has some type of electronic computer. An IBM 650 magnetic drum calculator was installed in the Coast and Geodetic Survey in May 1957. This computer is classed as a medium sized calculator and is found to be adequate for the present needs of the Bureau. The Computing Section is assigned to the Triangulation Branch for administrative direction but the group is asked to assist in the reduction of scientific and engineering problems for all other Divisions of the Bureau as well as care for fiscal and accounting processing.

Because of the availability of a high-speed computer, assistance was given to Brig. Martin Hotine and Mr. H. H. Brazier of the British Overseas Survey in the application of 3-dimensional techniques for the adjustment of triangulation and trilateration. The experience gained in the development of mathematical procedures and programs for this 3-dimensional method of adjustment has been very helpful in the development of programs for the analytical adjustment of aero-triangulation for the Photogrammetry Division.

The same techniques for the treatment of geodetic and photogrammetric data can be applied to observational data obtained from

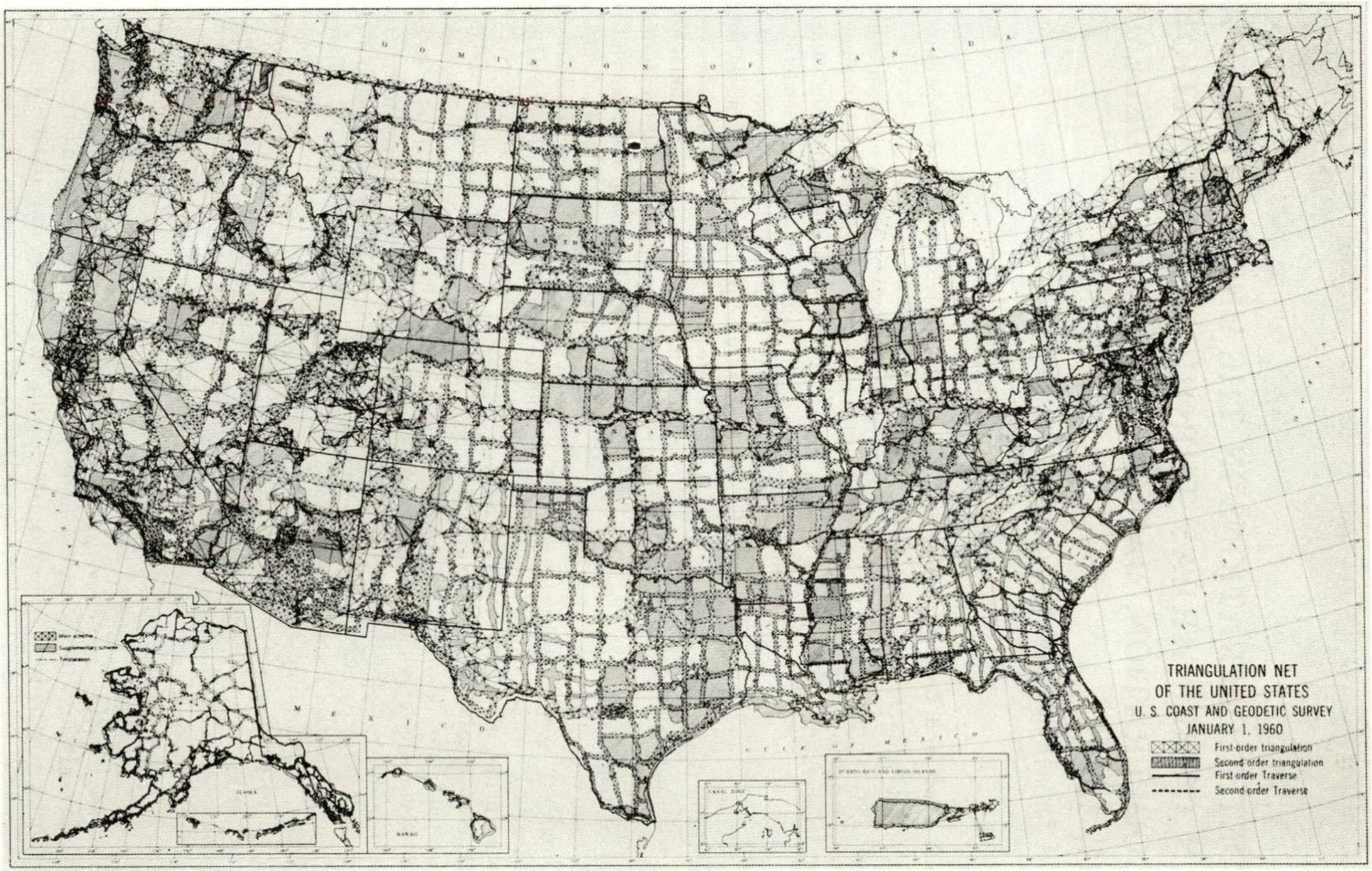

FIGURE 1.—Triangulation net of the United States.

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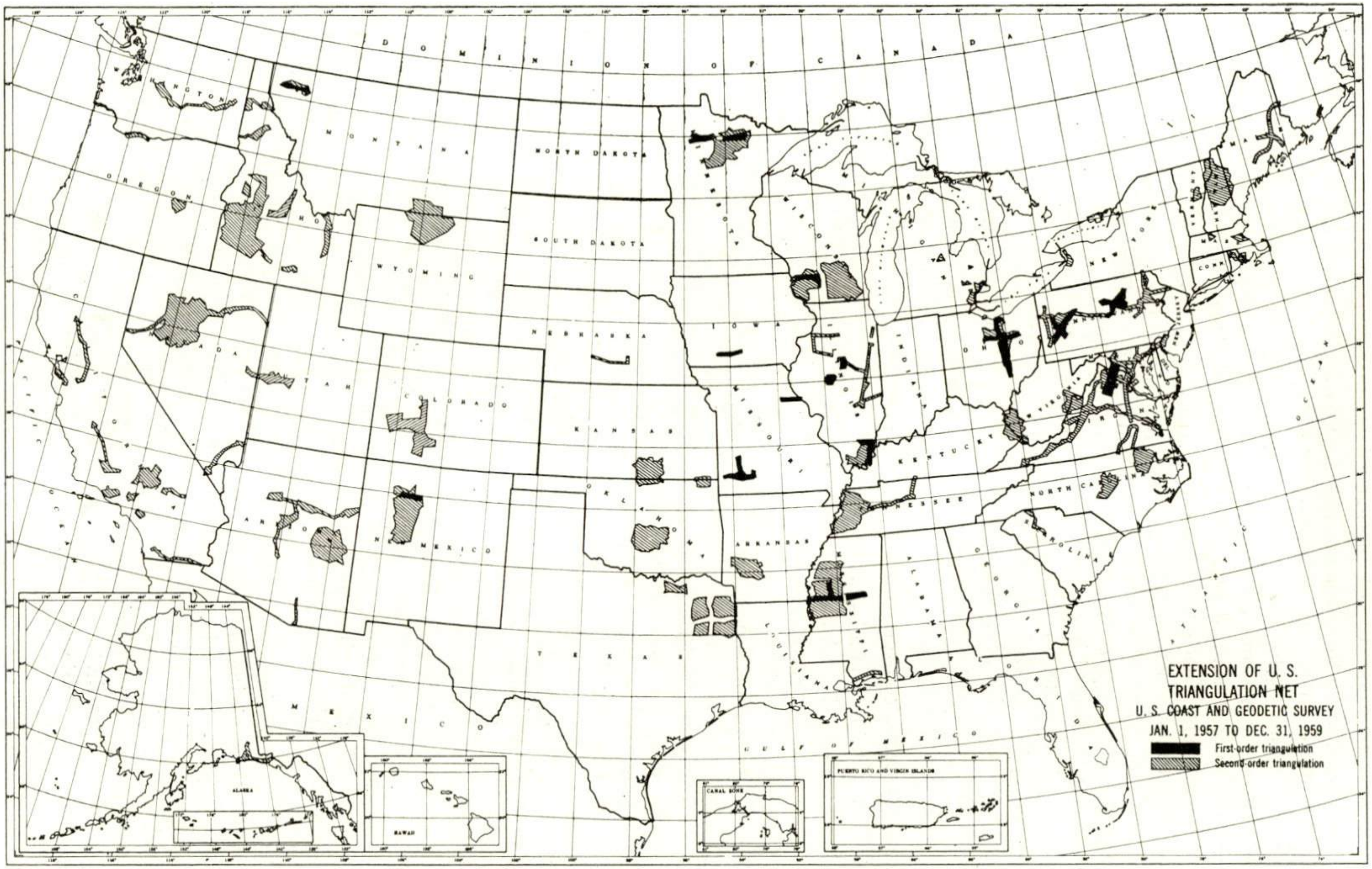

FIGURE 2.—Extension of the triangulation net of the United States.

flash rockets or satellites. At the present time, plans are being made for the launching of a geodetic satellite which may be used by geodesists of all countries, for the extension of their own geodetic networks, connection to islands or outlying areas, and even intercontinental connections. The same data may then be used for a more accurate determination of the size and shape of the earth.

The program for the reobservations of networks of geodetic control in seismic areas was continued. A more detailed description of this special type of geodetic survey will be found in the report to the International Association of Seismology and Physics of the Interior of the Earth.

ETHIOPIAN GEODETIC CONTROL PROJECT

Late in 1956 a Joint Commission of the International Cooperation Administration and the Ethiopian Imperial Government requested, through the Secretary of Commerce, that the Coast and Geodetic Survey enter into an agreement for the establishment of a geodetic control system in Ethiopia. The area of interest comprises an extensive unsurveyed and unmapped region of the drainage basin of the Blue Nile River. The cost of this project is to be shared equally by the United States and the Ethiopian Governments. The United States has provided about 12 technicians, including the chief of party, recruited from the ranks of the Coast and Geodetic Survey, while the Ethiopian Government has supplied a working force varying in number from, perhaps, 50 to 75 employees, consisting of civil engineers, trainees, and a variety of supporting personnel.

Arrival of the American technicians in Ethiopia began in the spring of 1957. Some months were spent in reconnaissance and in training personnel; the actual survey operations began late in 1957.

Operations involve first-order triangulation, including base lines, first-order leveling, and first-order astronomic observations. Connections were made to the geodetic surveys in the Sudan and in this way the Ethiopian triangulation net was placed on the African Datum which, in turn, is tied to the European Datum. At the end of 1959, the progress is as shown in figure 3. The total accomplishment at that time is indicated by the following statistics:

Miles of triangulation arc	1,840
Number of triangulation stations	251
Miles of leveling	1,469
Number of level bench marks	736
Number of base lines (totaling 48 miles)	7

U.S. Geological Survey

The topographic mapping activities of the Geological Survey require surveys to provide a geodetic-control framework. Most mapping needs are met by extending third-order control from the basic network of first- and second-order control covering the country.

During this 3-year period (1957–59), control surveys were conducted in the United States, Alaska, Hawaii, and the Virgin Islands. These surveys consisted of triangulation, traverse in which distances were measured electronically and angles by theodolite, transit-and-tape traverse, and leveling. Approximately 3,800 new triangulation stations were established. About 4,500 miles of Tellurometer traverse and 16,400 miles of transit-and-tape traverse were run.

Permanent marks were placed at the primary triangulation stations, along the traverse lines at 2- to 4-mile intervals, and at about the same intervals along lines of leveling. Positions and elevations for the monuments, and for other identifiable intermediate points, are published in separate lists covering 15-minute quadrangles. Besides providing a framework of control for the mapping, the control surveys of the Geological Survey are used extensively by other Federal, State, and private organizations wherever third-order control satisfies the needs of local projects.

The Bureau participated in scientific activities in Antarctica throughout the 3-year period. One engineer accompanied several

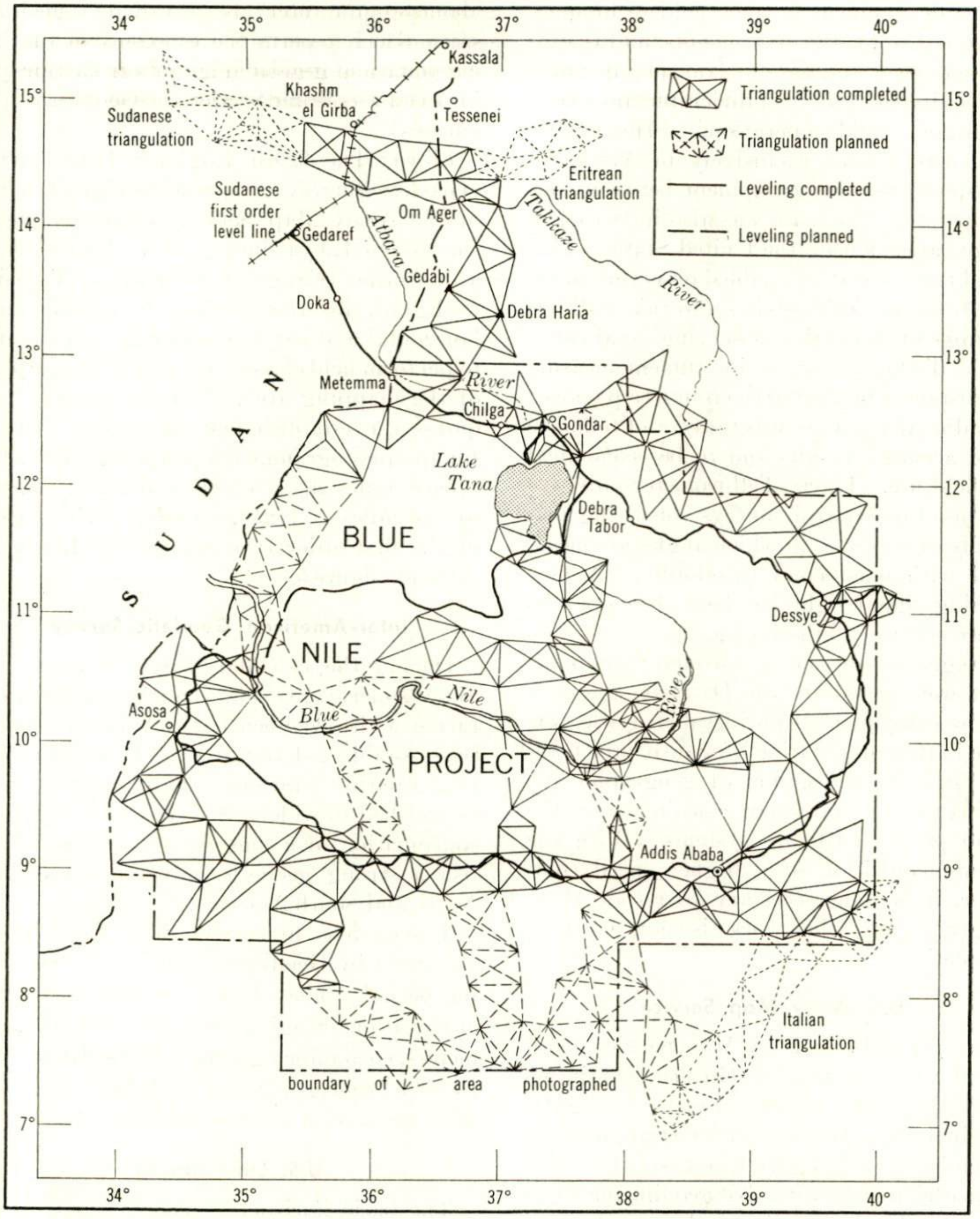

FIGURE 3.—Status of the Ethiopian geodetic control project, December 1959.

geophysical-traverse parties as navigator and determined geographic positions along the routes by astronomic observations made with a theodolite. The positions of nunataks and mountain peaks visible from the routes were determined by triangulation from measured bases. Two additional engineers were assigned to the work in 1959. They determined positions and elevations along geophysical-traverse routes and positions of identifiable points for the control of photogrammetric mapping.

The development of new field techniques, the use of improved instruments, and the increased speed and ease of transporting men and equipment by air in difficult terrain have facilitated field operations. Helicopters were used almost exclusively in Alaska to transport men and equipment between control points. Their use was also increased in remote areas within the United States. This rapid transportation enabled observers to arrive fresh at working sites and take full advantage of favorable observing conditions.

The Tellurometer, an instrument measuring distances by timing the round trip transit of radio microwaves, was tested and found to yield accurate results and to be economical for field use. Thirty Tellurometer units are now used on control surveys consisting primarily of traverses in which angles are measured with one-second theodolites. A new flashing signal light has been developed to insure certainty in pointing.

Programs for certain geodetic computations were coded for the Datatron 205 electronic computer. Considerable work was done in the computation of transit-tape traverse and the conversion of geographic coordinates to rectangular coordinates on the State plane-coordinate systems. With the recent acquisition of a higher speed computer, it became necessary to recode these programs and the work is now nearing completion.

U.S. Army Map Service

Iran: The U.S. Army Map Service cooperated with the Iranian Government in establishing first- and second-order triangulation in Iran. The first-order triangulation, which is shown in figure 4, consists of a chain of quadrilaterals with five geodimeter bases and seven Laplace stations. It extends from the Turkish border in the northwest to the Pakistan border in the southeast, and is connected to the first-order networks of Turkey and Pakistan (Survey of India triangulation).

Astronomic observations of latitude and longitude were made along this chain at about 30-mile intervals to provide a geoidal section which permits the extension of the computation of geoidal heights from Europe into India (see under Section: Geoid investigations).

Libya: The 329th Engineer Detachment (Geodetic Survey), a special foreign activity of the Army Map Service, conducted field surveys in Libya during 1957–59 to extend a first-order triangulation arc from Tunisia to Egypt, for the purpose of establishing horizontal and vertical mapping control and to perform field classification of photography of the mapping area. This assignment requires the establishment of survey control for the photogrammetric mapping of 41,200 square miles at 1/50,000 scale, and 55,800 square miles at 1/250,000 scale. The status of the first-order triangulation in Libya is shown in figure 5.

Inter-American Geodetic Survey

During the calendar years 1957–59, the Inter-American Geodetic Survey, in collaboration with seventeen Latin American countries, established 750 first- and second-order triangulation stations. This control was established in widely scattered areas and is a continuation of a long-range plan to establish a strong geodetic network connecting North and South America.

Twenty-five first-order base lines were measured by Geodimeter during the reporting period. These base lines were measured at elevations ranging from sea level to 4,500 meters, encountering temperatures from $-5°$ to $+29°$ centigrade and with humidities of 42 to 99 percent with no adverse effects.

U.S. Lake Survey

The basic horizontal geodetic control established by the U.S. Lake Survey consists of networks of first-order triangulation bordering the Great Lakes. These basic networks have been extended by second- and lower-order triangulation and by traverse in many areas to provide more closely spaced and more conveniently located stations for

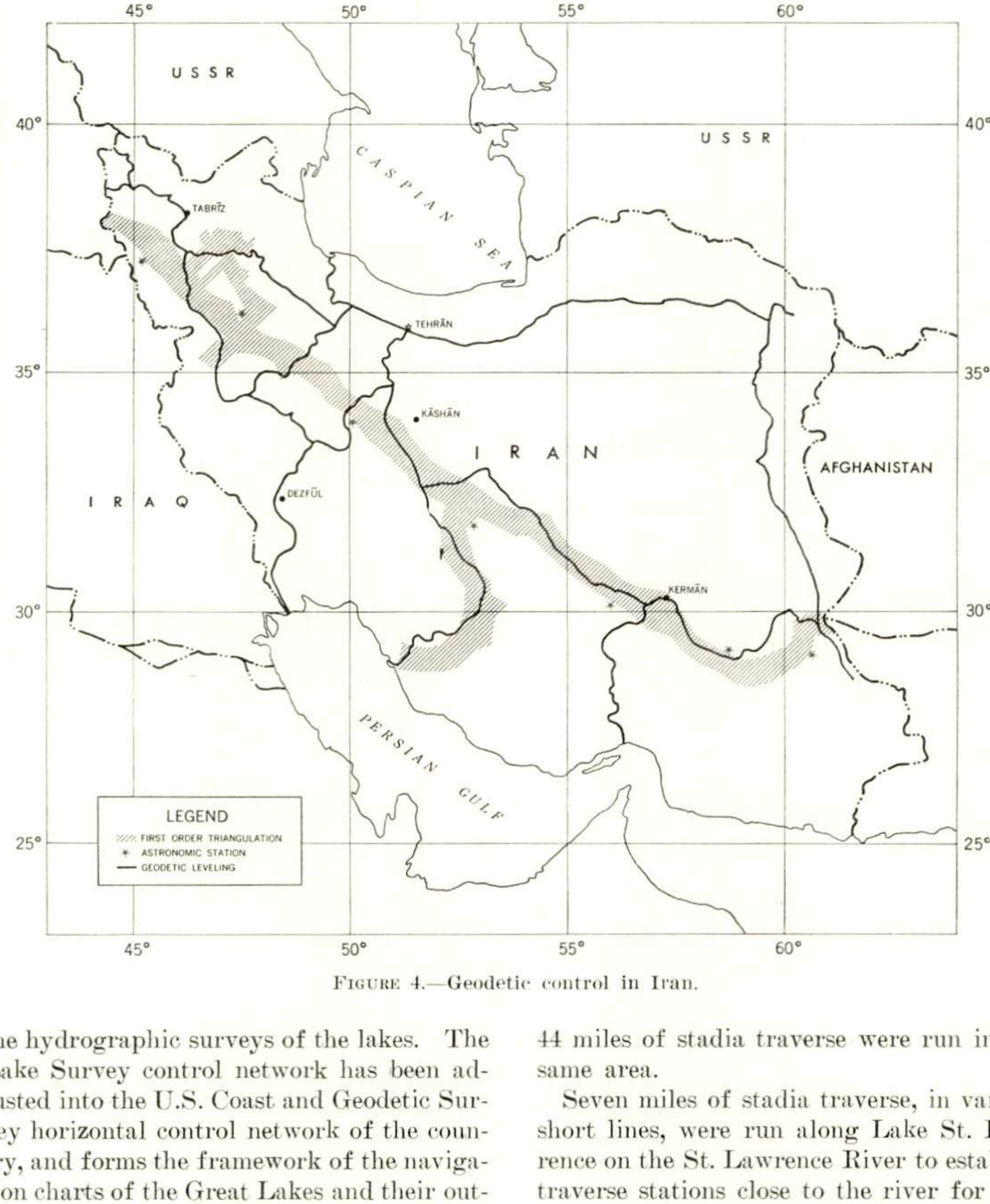

FIGURE 4.—Geodetic control in Iran.

the hydrographic surveys of the lakes. The Lake Survey control network has been adjusted into the U.S. Coast and Geodetic Survey horizontal control network of the country, and forms the framework of the navigation charts of the Great Lakes and their outflow rivers.

The only extension of the control network that is now required is the small amount made in connection with current hydrographic surveys. During the period 1957–59, 33 miles of Tellurometer traverse were run along the easterly end of Lake Ontario, and five permanently marked stations were established in the reach. In addition, about 44 miles of stadia traverse were run in the same area.

Seven miles of stadia traverse, in various short lines, were run along Lake St. Lawrence on the St. Lawrence River to establish traverse stations close to the river for control of a survey of the power pool of the new St. Lawrence River Power Project.

On Lake Huron, 120 miles of stadia traverse were run, and permanently marked traverse stations were established at about two-mile intervals.

The control work on Lake Ontario and on Lake Huron was in connection with resurveys of the shoal coastal waters that will be

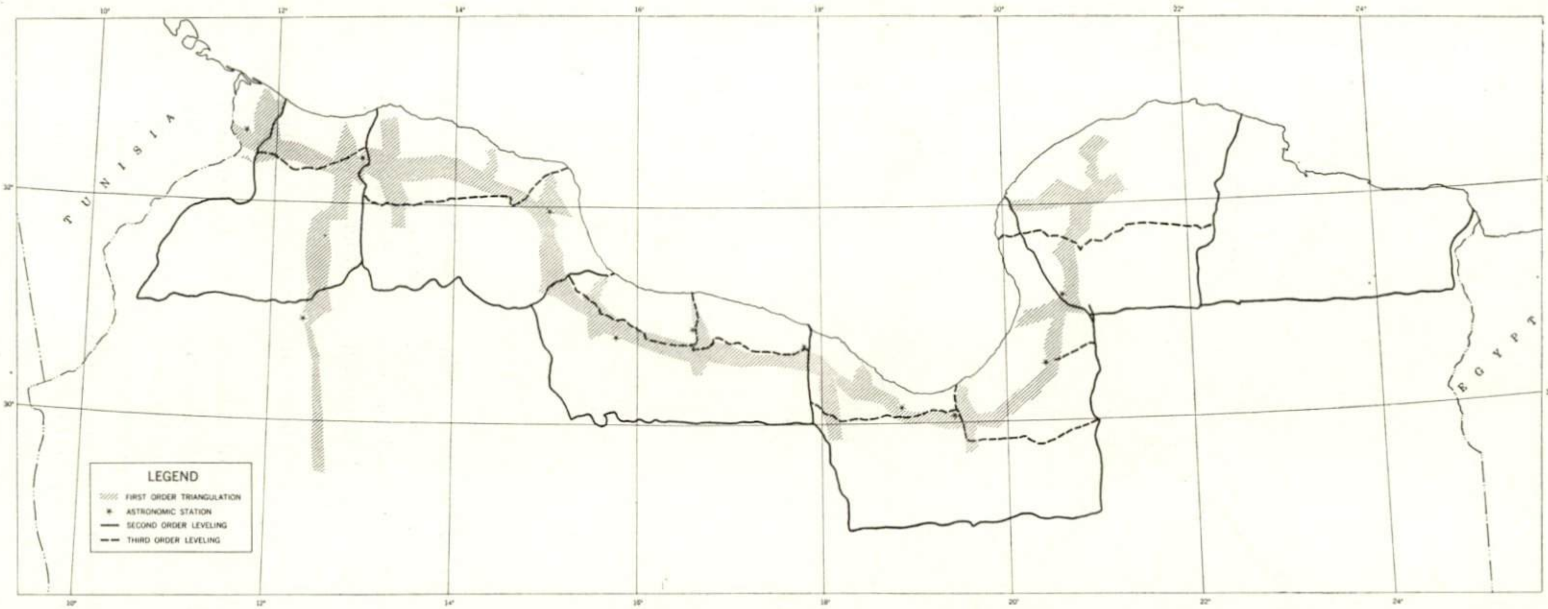

FIGURE 5.—Geodetic control in Libya.

used eventually to produce special charts for small-boat navigation.

During the period 1957–59, the Lake Survey also completed the program of adjustment of all second- and third-order triangulation into the nationwide horizontal control network of the U.S. Coast and Geodetic Survey.

U.S. Air Force

Geodetic operations on a global basis were conducted by the U.S. Air Force during the years 1957–59, using the HIRAN trilateration system of surveying. A small network connecting certain Brazilian islands to the mainland was completed during the previous reporting period but was not included in that report. A network diagram for this project is shown in figure 6.

Other projects completed or nearing completion at the close of this reporting period include the following:

Marshall Islands Survey. The long-range capability of the Hiran system permitted the formation of a local datum for this island group. By orienting the Hiran net with a Tellurometer traverse between two Hiran stations and with an observed astronomic azimuth over a relatively long line, and by referencing the net to gravity-corrected astronomic positions, the established geographic positions of the Hiran stations should be relatively close to true values. In addition to the nine Hiran stations positioned, thirteen secondary control points were established. A diagram of the network, which was completed in May 1959, is shown in figure 7.

Cuba—Central America Tie. A Hiran network closing the continuous loop of triangulation around the Gulf of Mexico by linking Cuba and Jamaica with British Honduras, Guatemala, and Honduras was com-

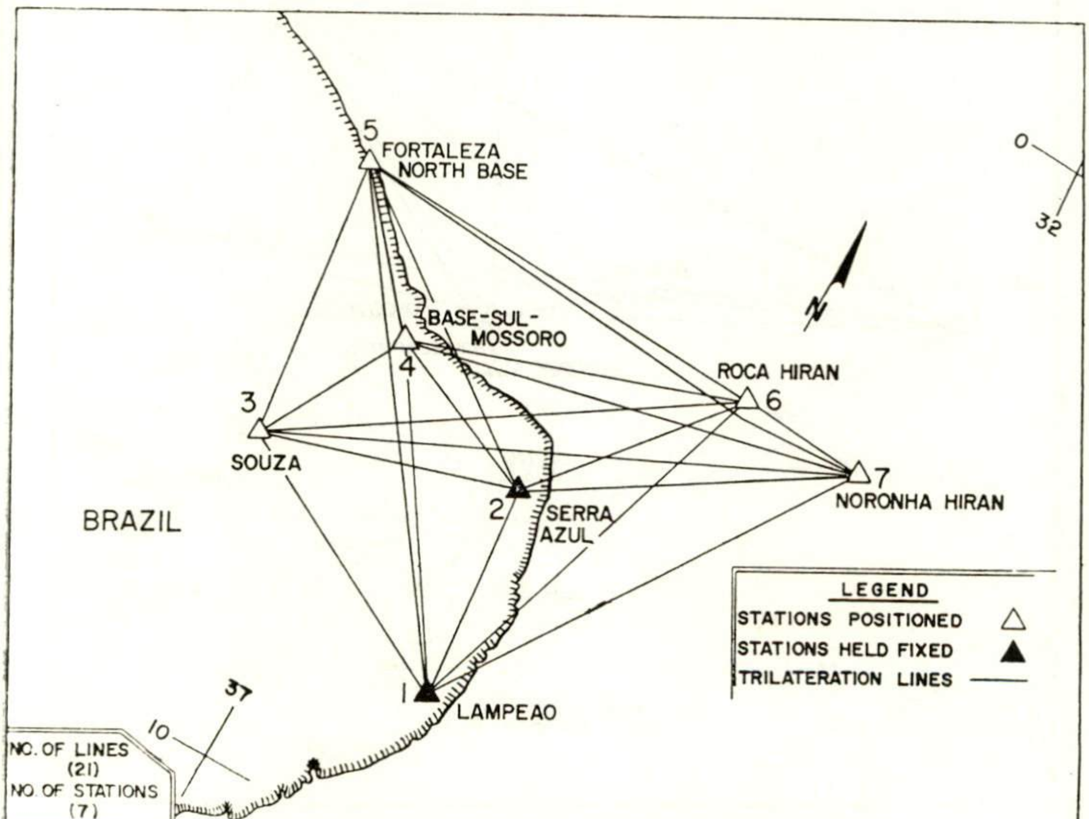

FIGURE 6.—Trilateration network, Coast of Brazil and nearby islands.

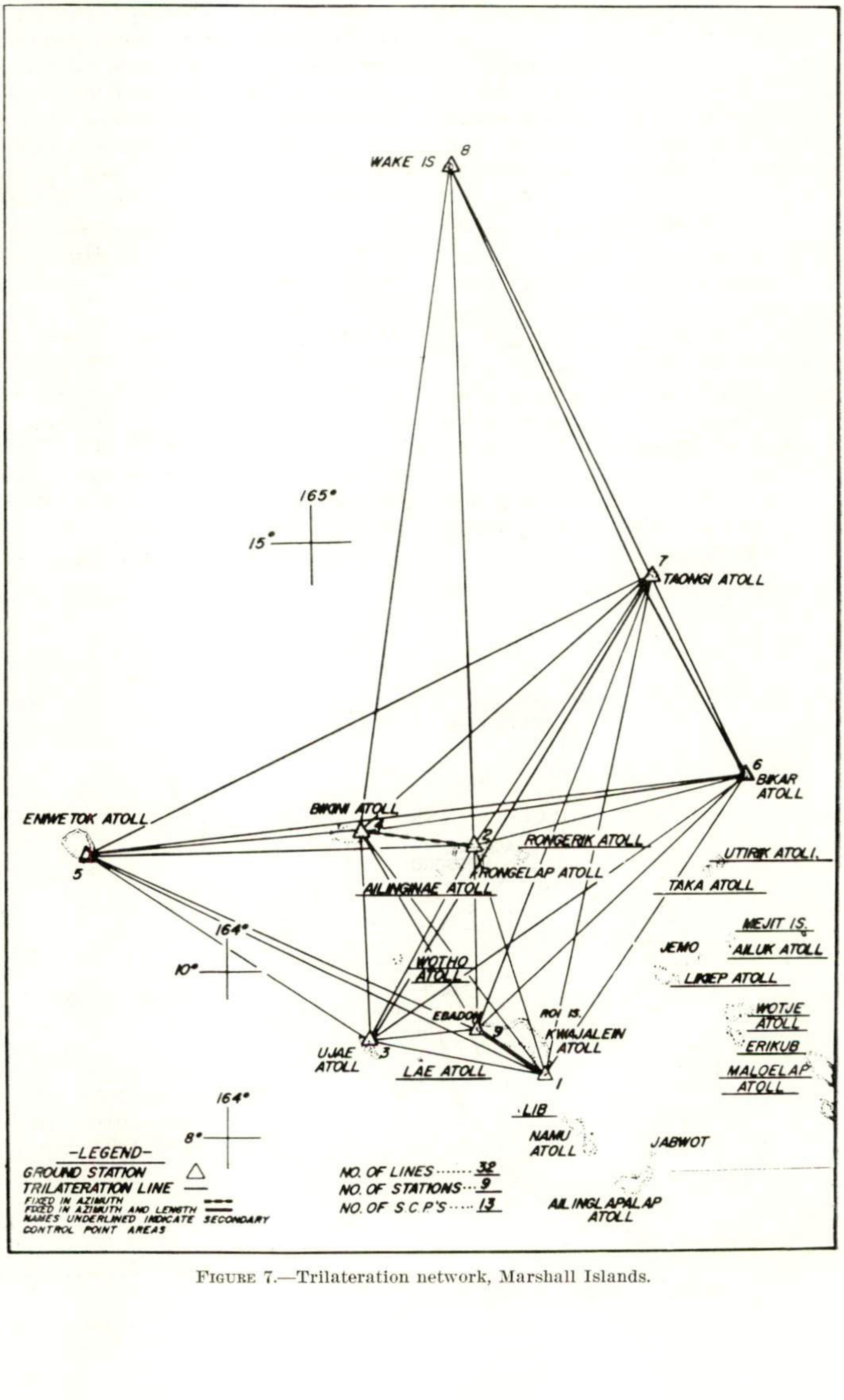

FIGURE 7.—Trilateration network, Marshall Islands.

pleted in December 1959. Secondary control points were established at points on Little Cayman and Cayman Brac. A network diagram is shown in figure 8.

Formosa—Ryukyu Tie. This network, composed of 12 Hiran ground station sites and 35 lines, connects Formosa with 6 of the Ryukyu islands and the Dacto islands and is nearly completed as of this reporting date. A network diagram is shown in figure 9.

Preliminary field reconnaissance is presently under way for a major Hiran project along the northeast coast of South America, connecting the existing triangulation in Venezuela with the triangulation near Recife, Brazil. A network diagram is shown in figure 10.

U.S. Navy Hydrographic Office

During the period covered by this report the Hydrographic Office conducted local triangulation surveys for the control of hydrographic surveying at Subic Bay, Philippine Islands, Kwajalein Island, and various locations in Labrador, Newfoundland, Canada, and the West Indies.

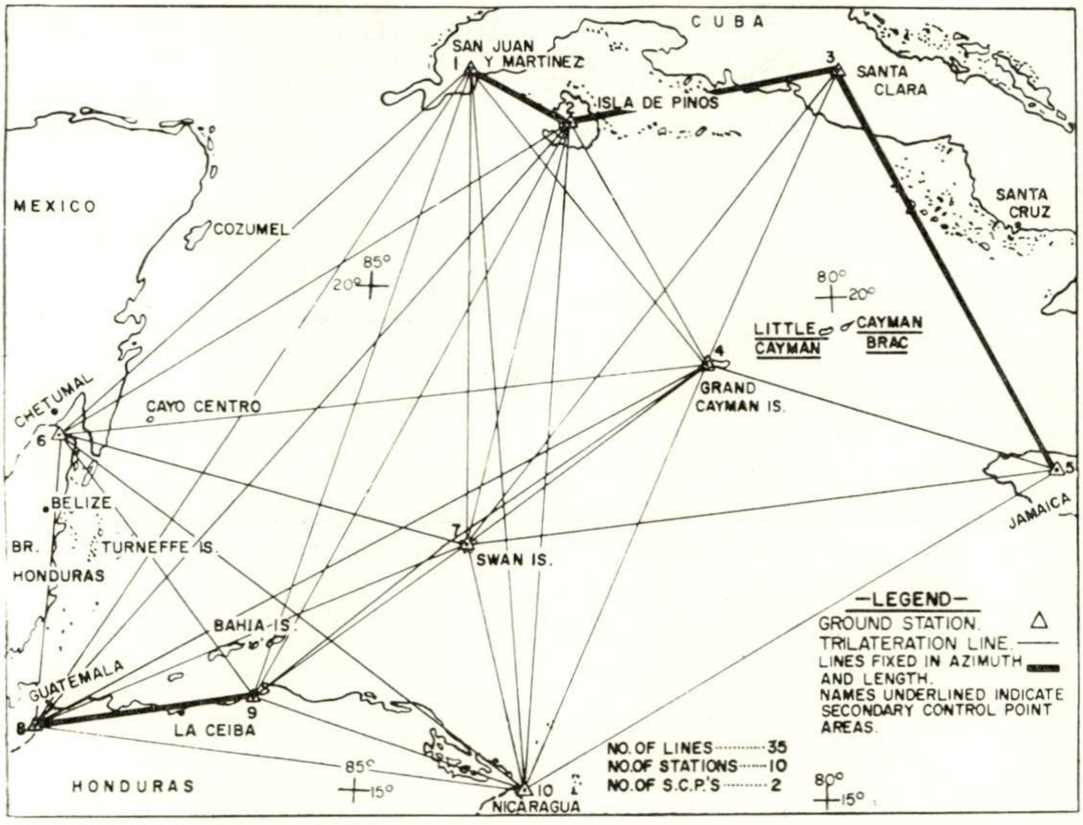

FIGURE 8.—Trilateration network, Cuba—Central America.

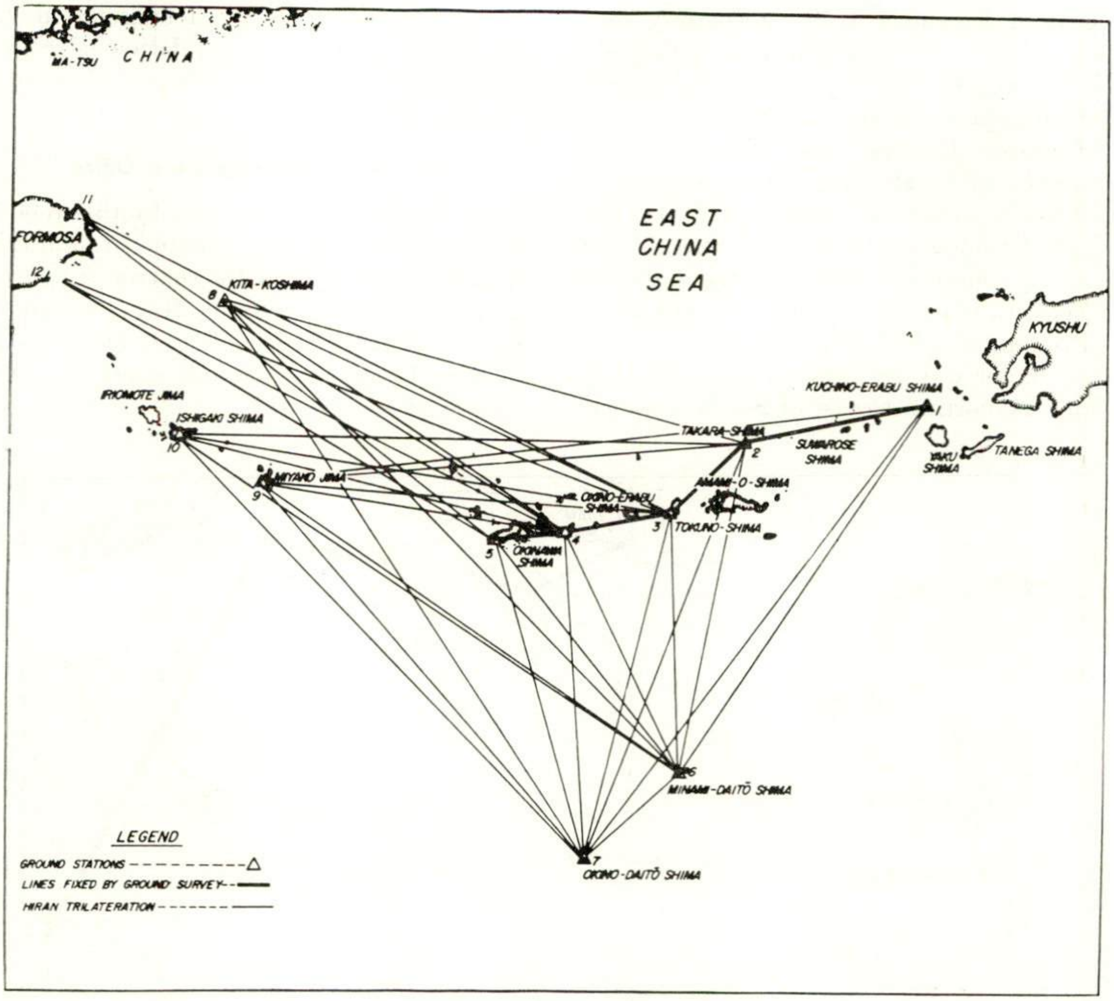

FIGURE 9.—Trilateration network, Formosa-Ryukyu.

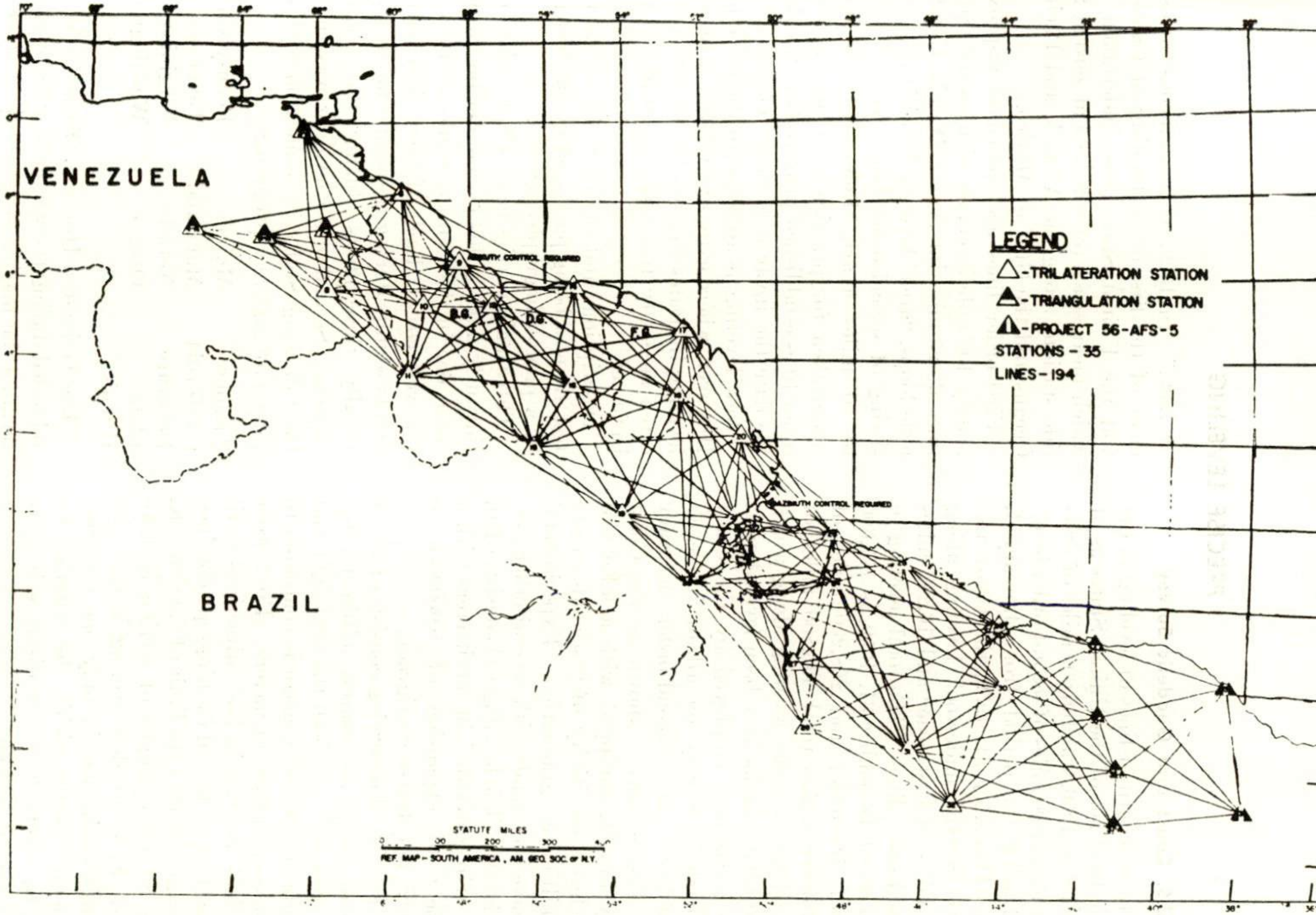

FIGURE 10.—Trilateration network, Venezuela-Brazil.

PRECISE LEVELING

U.S. Coast and Geodetic Survey

The total length of lines of leveling in the geodetic level net of the United States as of December 31, 1956, was 166,000 miles of first-order and 252,000 miles of second-order leveling. During the period from January 1, 1957, to December 31, 1959, the Coast and Geodetic Survey undertook leveling along 11,583 miles of first-order and 16,282 miles of second-order lines. The total leveling in the net as of December 31, 1959, is 177,600 miles of first-order and 268,200 miles of second-order which total 445,800 miles of first- and second-order leveling along which 380,000 bench marks have been leveled over.

The instrument employed by the Coast and Geodetic Survey on all of its leveling of first- and second-order accuracy is the Fischer level (known as the Coast Survey Level), equipped with a level vial which has a sensitivity of 2 seconds of arc per 2 millimeters graduation. Experimental tests have been made with several other precision levels. The leveling rod consists of an invar strip graduated in centimeters with a coefficient of expansion of 0.0000005 to 0.0000025 per degree centigrade.

The method of observing consists of direct rod readings to the nearest millimeter for three cross hairs on both the backsight and foresight, for which a mean is computed to four decimal places in meters. First-order level lines are run in both directions until forward and backward runnings are obtained which agree within the limit of 4.0 mm.$\sqrt{K}$, where K is the length of section in kilometers. Second-order leveling is run with the same equipment in only one direction with loop closures within the criterion 8.4 mm.$\sqrt{K}$, where K is the distance in kilometers around the loop.

Elevations of bench marks in the geodetic level net are based on the "Sea Level Datum of 1929." In 1929, a simultaneous adjustment of the first-order leveling of Canada and the United States was undertaken in which mean sea level was held at zero at 26 tide stations along the Atlantic and Pacific Oceans and the Gulf of Mexico.

First-order lines are spaced at approximately 100-mile intervals with second-order lines at 25-mile intervals. Within the 25-mile loops, "area" leveling is being run consisting of second-order lines spaced from 5 to 10 miles apart. Releveling has been undertaken for practically all of the first-order lines established prior to 1916 which is the date the invar rods came into use.

New leveling is adjusted to the basic net. However, where extensive releveling or new leveling indicates changes in elevations, it is often necessary to readjust portions of the basic net.

Descriptions and elevations in meters and feet are now being published by quadrangles by a photolithography process.

Three main parties have been leveling continuously during this period, one on the east coast, one in the Central States, and one on the west coast. Each of these field parties had two units during the winter months and usually three units during the summer months. Second-order leveling was run in the following States in connection with the interstate highway program:

Arizona	Maine	Pennsylvania
California	Maryland	Tennessee
Delaware	Nevada	Virginia
Idaho	Oregon	Washington
Illinois		

The Galveston-Houston, Texas area was releveled during the winter of 1958–59 to determine the magnitude and extent of settlement. Releveling of this net of lines is scheduled at 5-year intervals.

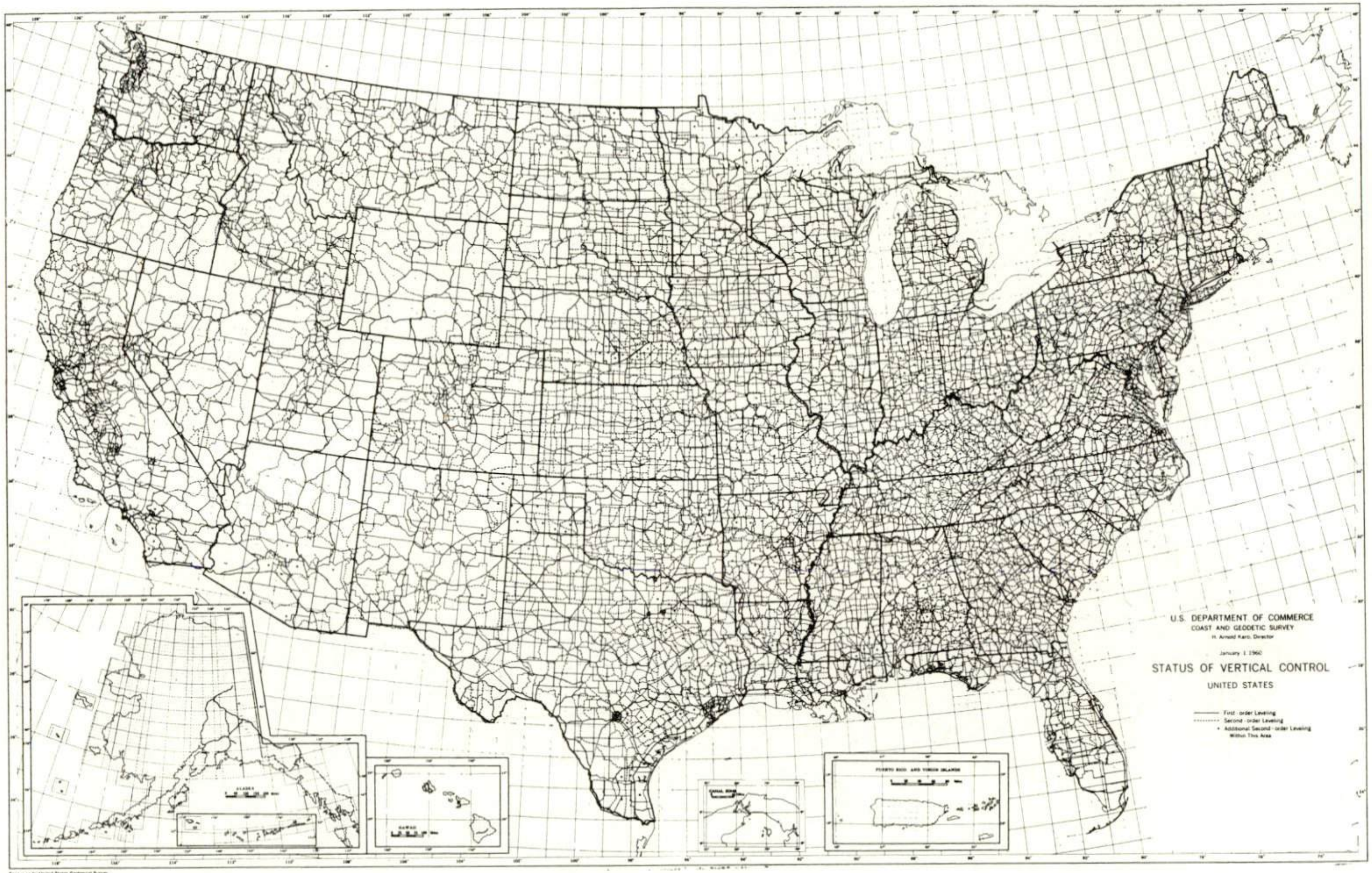

FIGURE 11.—Level net of the United States.

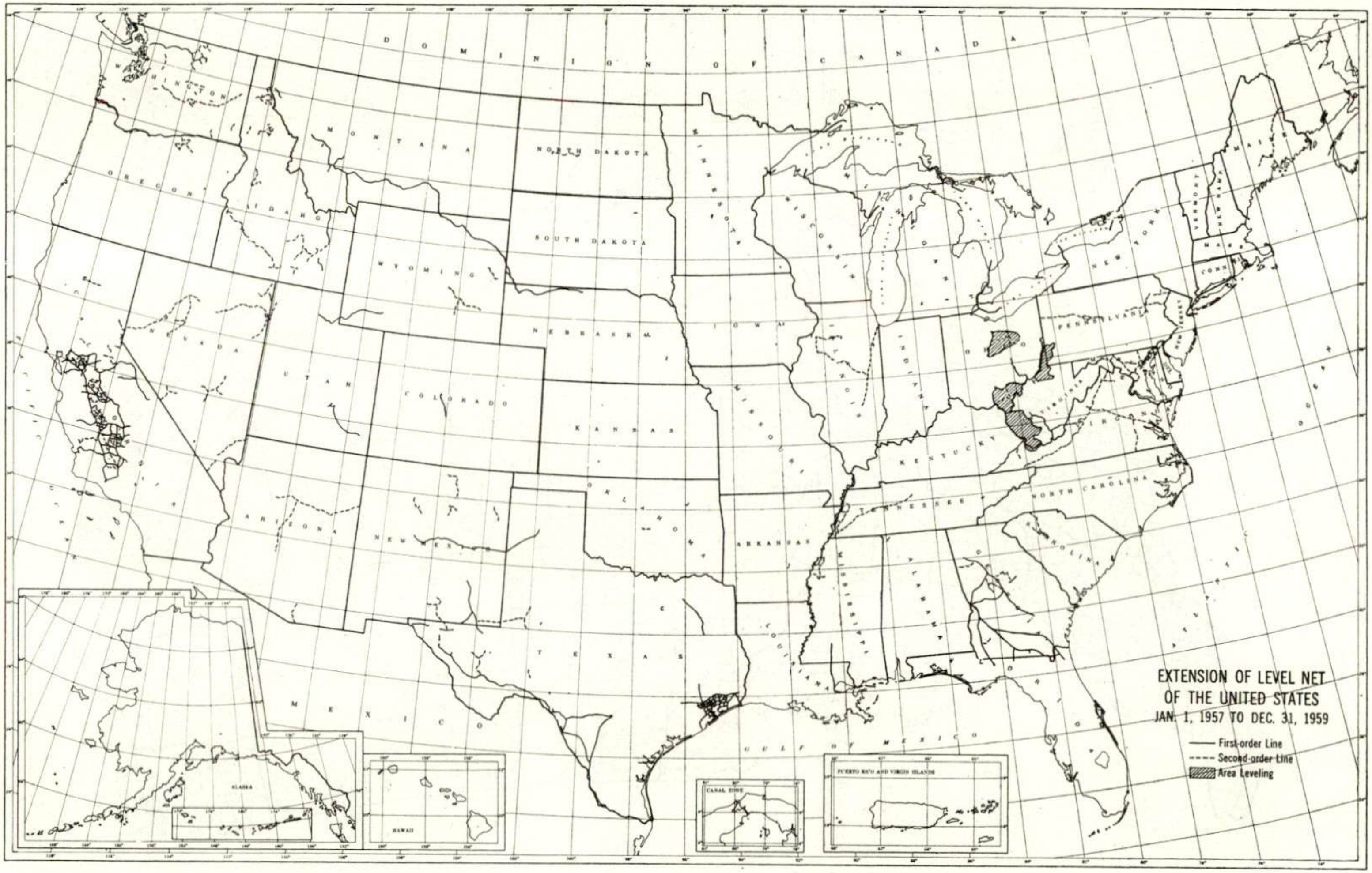

FIGURE 12.—Extension of the level net of the United States.

In the San Joaquin Valley of California, a releveling of certain portions has been scheduled at 2-year intervals. This releveling is being done at the request of the "Inter-Agency Committee on Land Subsidence in the San Joaquin Valley" for the purpose of studying the rate of settlement. Lines are extended to provide as many anchors in granite as possible.

A line of leveling was rerun in the vicinity of Hebgen Dam, Mont., following the earthquake of August 17, 1959, in that region, to determine the earth displacement. The maximum settlement measured was 18.86 feet.

The type of bench mark most frequently established is the concrete post which is about 4 feet in length, about a foot in diameter, and weighs about 600 pounds. Since one of the very important items in leveling is the establishment of marks that will remain stable, basic marks are now installed at 5-mile intervals. These marks consist of copper-coated steel rods driven to considerable depth.

Each of the level parties is supplied with a gasoline hammer for driving these rods which are ½ inch in diameter and 8 feet long. The 8-foot sections are coupled with a brass coupler and the rods driven to refusal. After reaching refusal the rods are cut off at the ground level and a disk compressed to the rod. Usually if refusal has not been reached at 50 feet, driving is sufficiently difficult to furnish a stable mark; however, some rods have been driven to depths of 110 feet. Supplementary marks consisting of copper-coated nails and brass washers are now being placed in roots of large trees.

Metal posts with an attached aluminum sign bearing the legend "WITNESS POST—PLEASE DO NOT DISTURB NEARBY SURVEY MARKER" are now placed near our bench marks.

Due to changes that are often necessary in the elevations of bench marks, the practice of stamping elevations on bench mark disks has been discontinued. A new bench mark disk is now in use by our level parties. It is the same as that used for tidal bench marks, except it does not have the circle at the center.

U.S. Geological Survey

During the period of this report (1957–59), the Geological Survey ran 43,100 miles of leveling, mostly of third-order accuracy. About 500 miles of double-run, second-order leveling were extended in areas where the basic network is sparse. Monumented bench marks were established at intervals of 2 to 3 miles along the lines.

About 75 percent of the leveling was done with automatic pendulum-type levels which gave satisfactory third-order results. Most of the networks were adjusted on the Geological Survey Electrical Survey Net Adjuster, an analog computer which yields results equivalent to a rigid least-squares adjustment but saves time.

The Johnson elevation meter, a self-propelled vehicle for determining elevations, was used on a number of projects to provide fourth-order vertical control for photogrammetric mapping. About 6,000 miles of leveling were completed with this equipment. The instrument integrates electrically the product of the distance measured by a fifth wheel, and the sine of the slope angle of the road surface, measured by a pendulum. Where an adequate network of roads exists in the area to be mapped, elevations of sufficient accuracy for supplemental control are obtained much faster than by any of the conventional methods of fourth-order leveling. The Geological Survey is purchasing two new elevation meters with transistorized electronic circuitry to further speed field operations in supplemental control.

Inter-American Geodetic Survey

The Inter-American Geodetic Survey has continued to assist Latin American countries in development of a network of geodetic leveling. The work has included determination of mean sea level by tide-gaging methods. During the period covered by this report 24,280 kilometers of first-order levels have been run. Since 1946, when this collaborative program began, a total of 128,000 kilometers of first-order line have been accomplished and the elevations determined for more than 65,000 bench marks. The first-order network is continuous from the United States to Chile with the exception of a break in Panama where there are no transportation facilities by land through the Darien region adjacent to Colombia. From Chile the leveling extends eastward through Bolivia and Brazil to the Atlantic coast.

U.S. Lake Survey

The vertical geodetic control established by the U.S. Lake Survey consists of groups of bench marks in 106 harbors on the Great Lakes and 500 miles of level lines of special first-order accuracy along the outflow rivers of the lakes. Elevations of the bench marks are listed on the U.S. Lake Survey 1935 Datum.

This datum was established in the following manner: In 1903, the U.S. Coast and Geodetic Survey made an adjustment without applying the orthometric correction, based on level lines and tide gage records in the United States east of the Mississippi River. The elevations of bench marks on the Great Lakes included in this adjustment were adopted by the Lake Survey and were designated as being on the U.S. Lake Survey 1903 Datum. This datum was extended to all major harbors on the Great Lakes and along the outflow rivers by the Lake Survey and the Canadian Hydrographic Service.

By 1935, differential movement of the earth's crust was causing gages on the same lake to show appreciable differences in water surface elevations, requiring the establishment of a new datum. A control point was chosen on each lake: Oswego, N.Y., on Lake Ontario, Cleveland, Ohio, on Lake Erie, Harbor Beach, Mich., on Lake Michigan-Huron, and Point Iroquois, Mich., on Lake Superior; and the bench mark elevations at the control points were held as given on the 1903 datum except for Point Iroquois, where the elevations were derived from Harbor Beach by water level transfer and levels of 1934 between Lake Huron and Lake Superior. Bench mark elevations at other sites on the U.S. side of the Great Lakes were computed from these control points by water level transfers supplemented by local leveling and the resulting elevations were said to be on the U.S. Lake Survey 1935 Datum. In other words, the elevations derived were the elevations of the bench marks in 1935 with respect to their particular control point.

At the present time, the Lake Survey is collaborating with three Canadian agencies, the Department of Northern Affairs and National Resources, the Department of Mines and Technical Surveys, and the Department of Transport, in the establishment of a new datum that will be called the International Great Lakes Datum, 1955. This datum will be based upon the mean water level at the outlet of the Great Lakes system in the Gulf of St. Lawrence; specifically, upon the mean water level as measured by the tide gage at Father Point, Quebec. The dynamic numbers that will be determined for the bench marks will be adopted as their elevations on the new datum. The Chief of Engineers, U.S. Army, has approved the adoption of the new datum in the United States and early use of it on Lake Ontario and the St. Lawrence River by both countries is now under consideration.

The equipment employed by the Lake Survey in leveling of special first-order accuracy consists of the Zeiss Opton self-leveling level and U.S. Coast and Geodetic Survey rods. The method of observing consists of direct rod readings to the nearest millimeter of three cross hairs on both the backsight and foresight, for which a mean is computed to four decimal places in meters. Lines are run in both directions until forward and backward runs are obtained that agree within the limit of 3.0 mm. $\sqrt{K}$, where K is the length of the line in kilometers.

Transfer of elevations by water levels is made between harbors on the same lake by comparisons of gage records at the harbors involved. Only the records of the months June through September, when the lakes are not influenced by wind and barometric disturbances to any major degree, are used. Transfer to a given point on a lake is made from two or more gage sites where elevations have been established previously.

At the sites of bench mark groups where water level gages are not maintained continuously, temporary gages are installed on the average of once every ten years to check the stability of the groups and the rates of crustal movement of the earth. In addition, all of the bench marks are recovered triennially and second-order levels are run between the bench marks of each group to check their relative stability. Bench marks along the outflow rivers are recovered periodically and the level lines are rerun for a similar purpose. Bench marks established and maintained by the Lake Survey, in addition to being used for control of hydrographic surveys for the navigation charts and for study of the hydraulics of the Great Lakes, are used to control the federal navigation projects by other Corps of Engineer Districts. They are also used by many other government agencies and by a number of industries concerned with the levels of the lakes and rivers.

During the period 1957–59, the Lake Survey ran 436 miles of special first-order levels, involving 829 bench marks. Most of these levels will be used in connection with the establishment of the International Great Lakes Datum, 1955. Lines were run as follows:

a. Along the U.S. side of the St. Lawrence River from Cornwall Island, Ontario, to Cape Vincent, N.Y., a distance of 132 miles, involving 190 bench marks.

b. Along Lake Ontario and the U.S. side of the Niagara River from Olcott, N.Y., to Lackawanna, N.Y., a distance of 65 miles, involving 89 bench marks.

c. Along Lake Erie, the U.S. side of the Detroit-St. Clair River system, and Lake Huron from Monroe, Mich., to Lakeport, Mich., a distance of 162 miles, involving 306 bench marks.

d. Along the Saginaw River from Essexville to Saginaw, Mich., a distance of 26 miles, involving 60 bench marks.

e. At various harbors on Lake Erie, a total distance of 10 miles, involving 44 bench marks.

f. At Wurtsmith, K. I. Sawyer, Selfridge, and Kincheloe Air Force Bases, a total distance of 41 miles, involving 140 bench marks.

During the St. Lawrence River leveling, three connections were made with a Geodetic Survey of Canada first-order level line. These connections were at Cornwall Island, at the Moses-Saunders Powerhouse near Cornwall, Ontario, and at Iroquois Dam near Iroquois, Ontario.

During the leveling from Lake Erie to Lake Huron, a first-order level line was being run along the Canadian side of the Detroit-St. Clair River system by the Geodetic Survey of Canada. The Lake Survey made two connections with this line across the Detroit River and the Geodetic Survey made two connections with the Lake Survey line across the St. Clair River.

The Canadian connections were from Port Lambton, Ontario, to Roberts Landing, Mich., and from Sarnia, Ontario, to Port Huron, Mich. The Lake Survey connections took advantage of islands in the Detroit River to reduce the lengths of the over-water lines. One connection was made from the U.S. mainland via Grosse Isle, Stony Island, and the dike along Livingstone Channel, to the Canadian mainland at Amherstburg, Ontario. The second connection was made from the U.S. mainland via Belle Isle to the Canadian mainland at Windsor, Ontario.

The average length of the over-water lines in these connections was 1,534 feet and the maximum length was 2,129 feet. The Lake Survey method of observing over these distances is as follows: The level is set up near the bench mark at one end of the over-water line and the rod is read on the near bench mark. A target is then set on the rod on the bench mark at the other end of the over-water line. The target is moved off setting and then reset on the far bench mark. This resetting is repeated at least eight more times. Extra settings are made to replace any settings that appear to be markedly different from the average. After the series of rod settings on the far bench mark is completed, a check reading is taken on the rod on the near bench mark. The level is then moved to the other end of the over-water line and the foregoing procedure repeated. Following this, the level is moved to another location near the same bench mark and the procedure repeated. The level is then moved back to the end of the over-water line where it was originally placed, is set up near the bench mark but not at the original set-up position, and the procedure is run a fourth time.

GEODETIC ASTRONOMY

U.S. Coast and Geodetic Survey

FIELD OBSERVATIONS

Observations of latitude, longitude, and azimuth in the United States and other areas were continued throughout the reporting period. These data were employed in control of triangulation arcs, deflection of the vertical determinations, detection of crustal movements in earthquake areas, and for other special purposes.

A total of 73 first-order latitude and longitude stations were observed. These included 19 stations for control of personal equation in second-order position observations on the 35th parallel geoid profile, and five Laplace azimuth stations on the Blue Nile triangulation project in Ethiopia. A large number of first-order astronomic positions were observed in the United States and other areas in connection with military requirements. A total of 41 astronomic azimuths were observed for triangulation control in the United States, Hawaii, Ascension Island, and Ethiopia.

Conventional meridian transits of the Bamberg and Wild T–4 types are employed in first-order position determination. Latitudes are determined from 15 to 20 Horrebow-Talcott star pairs. Longitudes are based on 5 to 7 sets of about 6 stars each, with WWV time signals recorded on drum chronographs and compared with mechanical chronometers at approximate 1-hour intervals.

In 1958 new equipment was adopted for the recording of first-order longitude observations, resulting in simpler operation, better performance, and reduction in weight. An electric-driven drum chronograph replaced the weight-driven type, reducing total shipping weight from 150 pounds to 15 pounds per unit. The vacuum-tube amplifier was replaced by a more compact transistor amplifier-filter having about 90 percent less battery drain and greatly improved response and stability. The new equipment performed reliably on five first-order stations in 1959 in Ethiopia, where WWV time signals were recorded with little or no difficulty.

Astronomic azimuths are usually observed with Wild T–3 theodolites, except that in high latitudes the Wild T–4 theodolite is employed. Close circumpolar stars at any hour angle are observed where possible. In equatorial latitudes, east and west stars are observed near elongation in the altitude range between 8 and 22 degrees.

Second-order latitudes and longitudes were observed at 133 stations on the 35th parallel geoid profile and at 21 other locations. Wild T–3 theodolites were employed, observing four east-west star pairs for longitude and Polaris with a matching south star for latitude. Personal equations were determined at approximate five-station intervals. The times of star pointings were estimated by the observer directly from continuously audible WWV one-second time signal pulses. Average internal probable errors of about 0.4 second of arc in each component were obtained with the second-order procedure. Considering slight variations in personal equation of the observer, an actual probable error of about 0.8 second of arc is indicated for longitudes observed by fully experienced personnel.

VARIATION OF LATITUDE

Two of the five northern-hemisphere International Latitude Service observatories on the 39th parallel were maintained in continuous operation by the Coast and Geodetic Survey at Gaithersburg, Maryland, and Ukiah, California. At Gaithersburg, 8,938 star pairs were observed on 773 nights, with complete observations on 218 nights. At Ukiah, 11,532 star pairs were observed on 726 nights with complete observations on 505 nights.

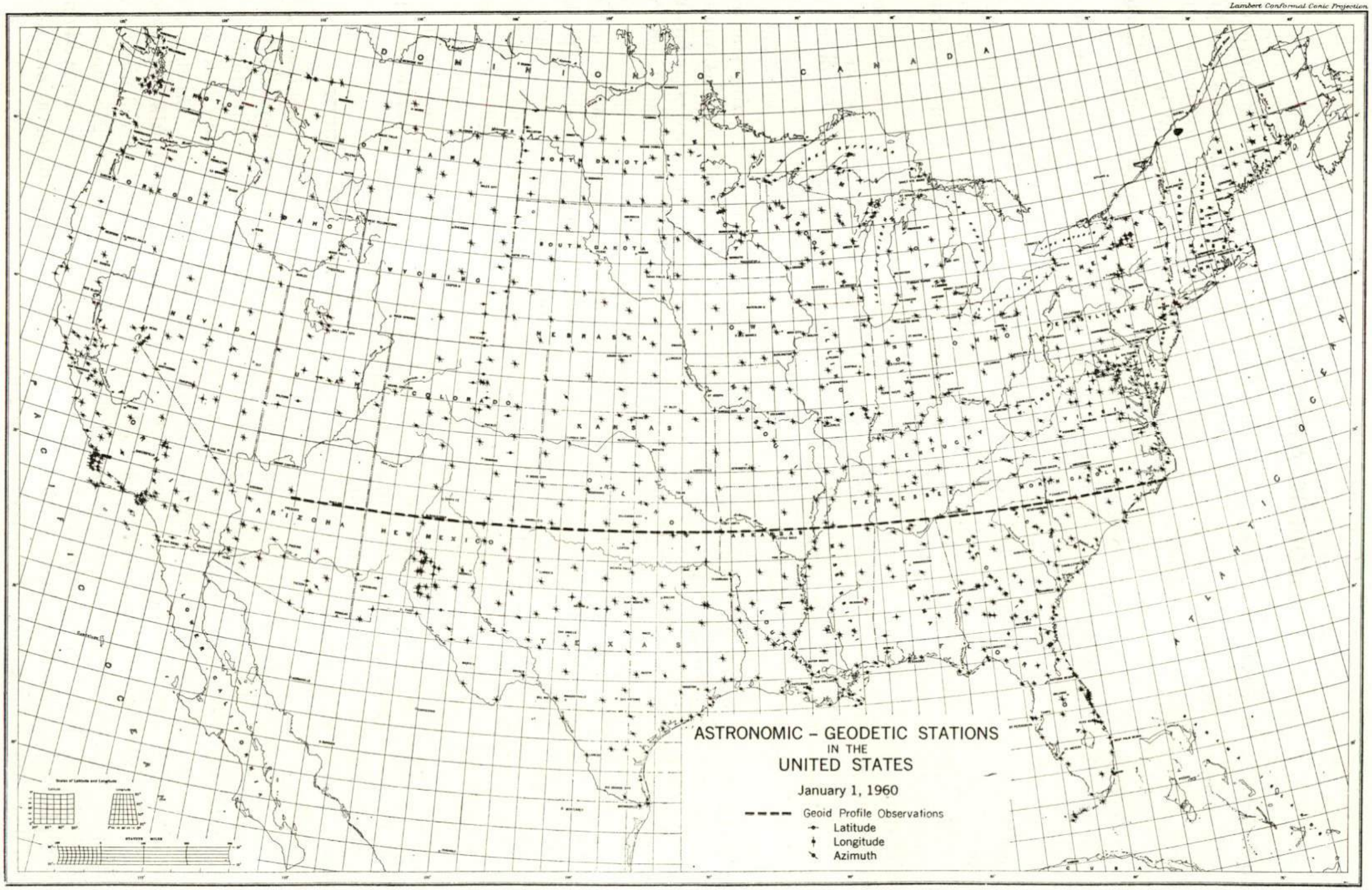

FIGURE 13.—Astronomic-geodetic stations in the United States.

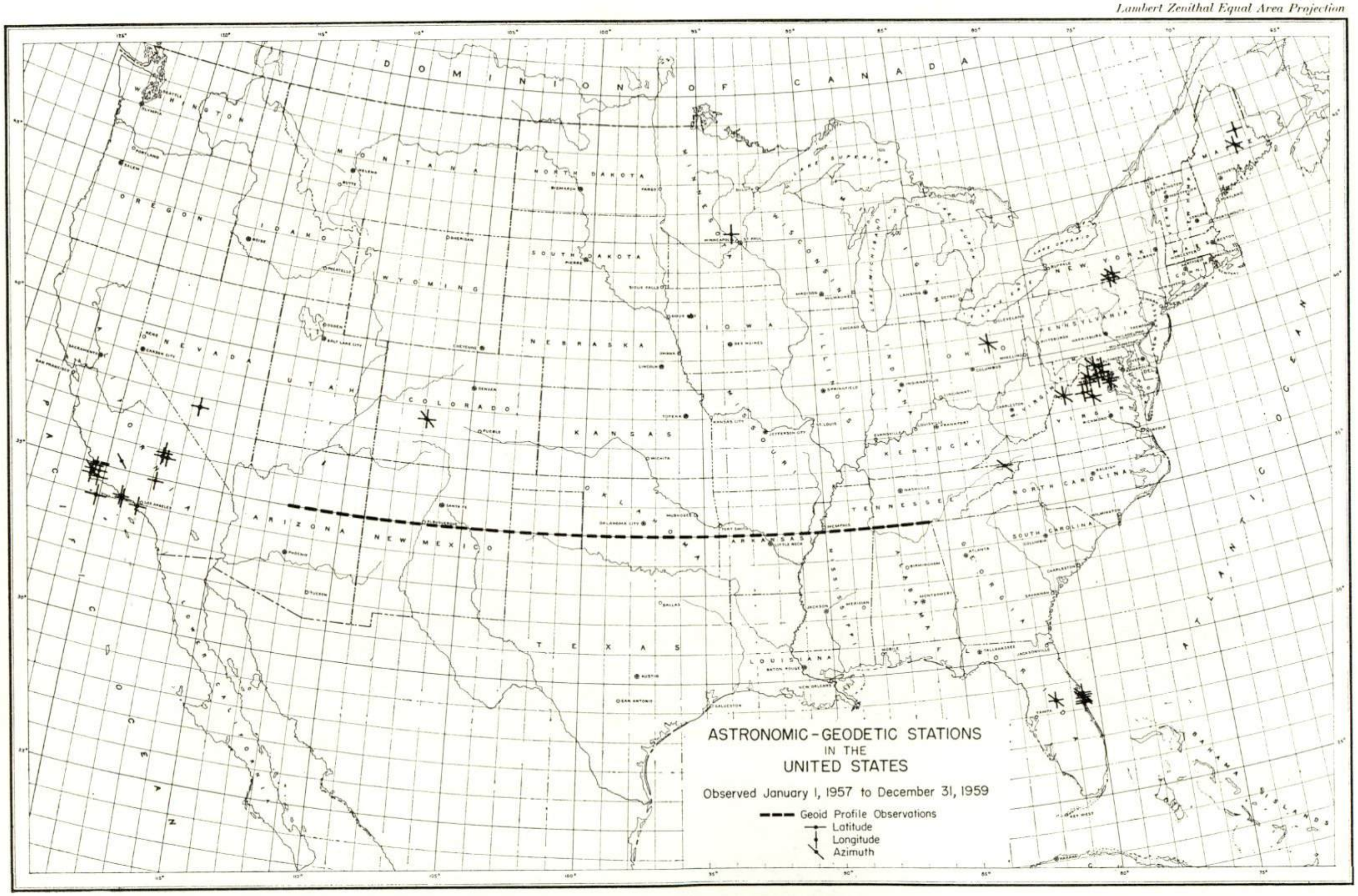

FIGURE 14.—Progress in astronomic observations in the United States.

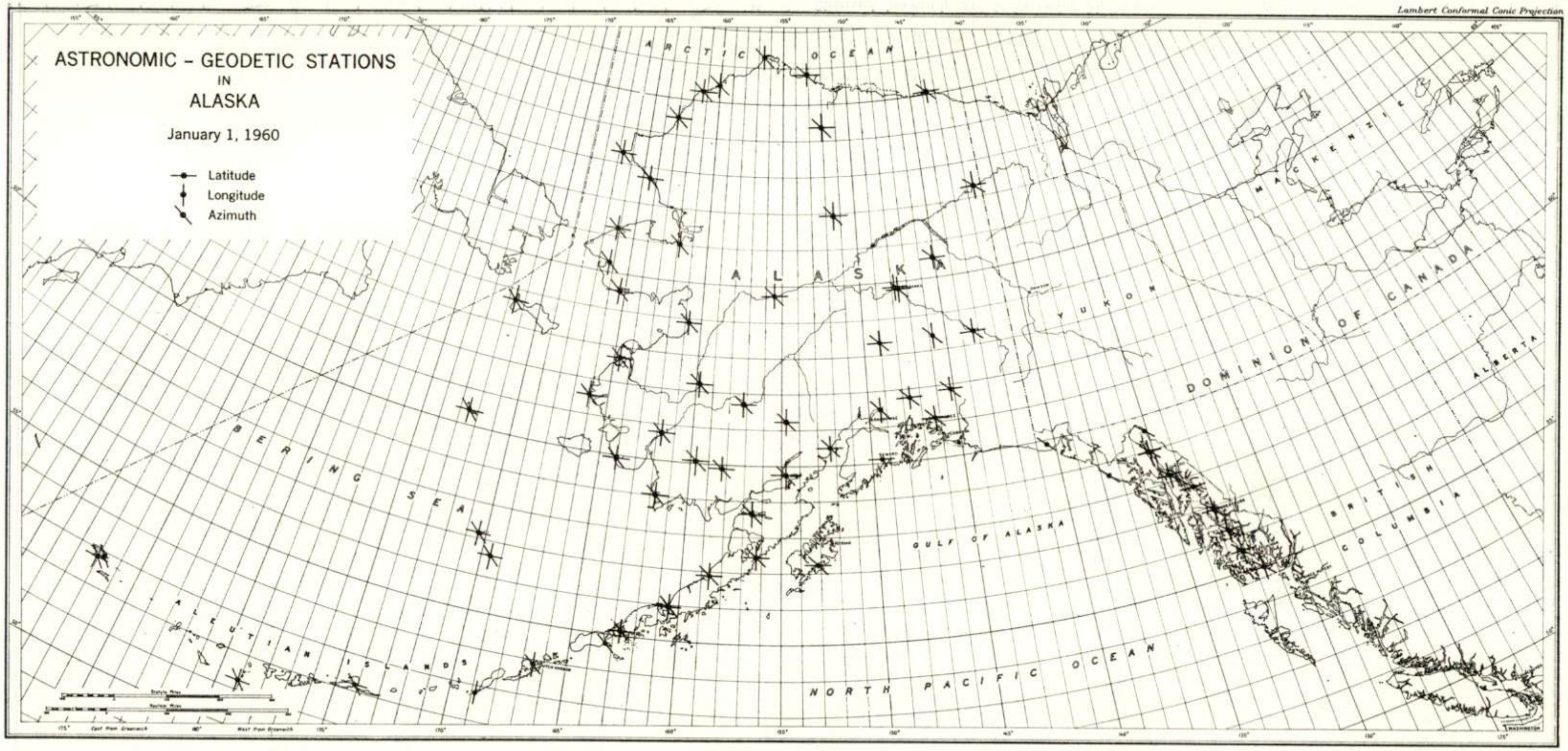

FIGURE 15.—Astronomic-geodetic stations in Alaska.

IGY LONGITUDE AND LATITUDE OBSERVATIONS

In early 1958 the Coast and Geodetic Survey established a temporary astronomic observatory at Honolulu, Hawaii, in cooperation with the IGY Longitude and Latitude program. The program involved continuous nightly observations with a Danjon impersonal astrolabe and a Markowitz dual-rate moon camera. The astrolabe position measurement program will aid in the detection of small intercontinental drifts and in studies of variation of the earth's rotation axis. The moon-camera data will be employed to determine the moon's position among the stars in connection with investigations of uniform time and new geodetic positioning applications. Time control was provided by a quartz clock monitored by time signals from WWVH on the island of Maui, Hawaii. Astrolabe observations were automatically recorded on tapes fed through a digital printing chronograph. At the conclusion of the observing period in December 1959, essentially complete astrolabe data had been observed on 362 nights and a total of 1,280 moon-camera plates had been obtained.

U.S. Army Map Service

Since January 1958, the U.S. Army Map Service has carried on radio interferometric tracking of artificial satellites at two stations on Pacific islands. Thus far, observations have been made on Luzon, Kwajalein, Guam, Wake, Ponape, and Samoa. At each station, three pairs of Mark II Minitrack antennas on 330-meter baselines were employed to receive the 108-megacycle signals transmitted by the satellites. The antennas were oriented by the tracking of radio stars; this orientation has proved to be the principal cause of inaccuracy in the system, and arrangements are being made to orient by the tracking of aircraft.

Occultation observations by photo-electric cells to obtain differences in latitude and longitude have been continued in Japan, the Ryukyus, the Philippines, Marcus, the Marianas, the Carolines, the Marshalls, Wake, Midway, Hawaii, and California. Up to June 30, 1959, 71 pairs had been successfully observed by U.S. Army Map Service, Far East. Accuracy of preliminary results is ±200 meters in each coordinate. Final results are not yet computed, but are awaiting completion of lunar limb mapping and an improved lunar ephemeris by the U.S. Naval Observatory.

Inter-American Geodetic Survey

Fifty-eight stations were occupied during the reporting period for observations of latitude, longitude, and azimuth. The average probable errors are: Latitude $\pm 0\overset{''}{.}06$; Longitude $\pm 0\overset{''}{.}06$; Azimuth $\pm 0\overset{''}{.}19$.

U.S. Air Force

One first-order astronomical station was observed in Columbus at the McMillin Observatory in order to provide a precise value for computation of the astro-gravimetric deflections in that area.

First-order astronomic positions were observed at each of the HIRAN locations in the Cuba—Central American Trilateration Network, as indicated in figure 16. The computations for this work were performed by the Inter-American Geodetic Survey.

U.S. Navy Hydrographic Office

During the period covered by this report first-order astronomic observations were made at Bermuda, Atol das Rocas, and Clipperton Island.

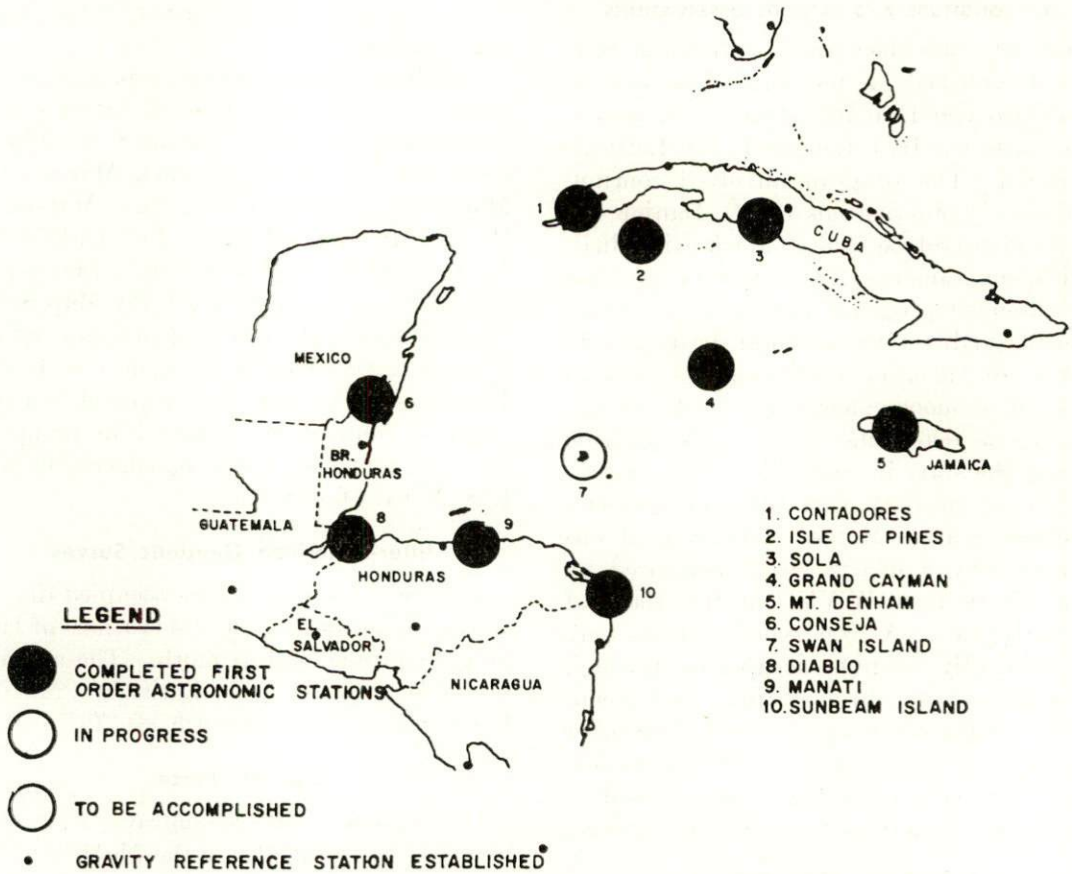

FIGURE 16.—Astronomic and gravity stations in Cuba and Central America.

GRAVITY OBSERVATIONS AND REDUCTIONS

U.S. Coast and Geodetic Survey

Gravimetric observations of the Coast and Geodetic Survey were accomplished entirely with gravity meters during the 1957–59 period.

Area gravity surveys were continued in Minnesota and adjoining States, involving a total area of approximately 60,000 square miles and completing a north-south belt of gravity coverage about 6° in width extending from the Gulf of Mexico to the Canadian boundary. Free-air and simple Bouguer anomalies are determined for area coverage stations, employing IBM equipment for computing and listing.

Several gravity meter traverses were measured to develop the basic control network and provide more accurate calibration standards. The first of these was a connection between the national bases at Washington, D.C. and Ottawa, Canada, with an additional tie to Idlewild Airport, New York City, one of the primary stations in the transatlantic gravity network. Early in 1957 the mid-continent gravity calibration line was traversed between Beloit, Kans., and Brownsville, Tex. During this operation, auxiliary stations were established in the vicinity of each control point to provide easier recovery and guard against possible destruction of station marks. An additional gravity traverse, consisting of 35 stations, was established between the national base in Washington, D.C. and Key West, Fla. for future gravity control along the east coast. During this operation, approximately 40 pendulum stations previously established in southern Florida were connected to the new network.

The gravity traverse between the national bases at Washington, D.C., and Ottawa, Canada, was rerun in November 1957 to strengthen datum and calibration comparison between the American and Canadian systems. During this operation a connection was made to the Montreal International Airport, the western terminus of a recently completed transatlantic gravity meter tie. Early in 1958 operations were resumed on the east coast base network between Washington, D.C., and Key West, Fla. About 165 pendulum stations were recovered and connected to the network. Wherever possible, nearby permanent points of known elevation were tied to the pendulum stations to aid in future recovery.

Special gravity measurements were made at instrument test facilities of the Martin Co. in Denver, Colo. and the Sperry-Farragut Co. in Bristol, Tennessee.

A new gravity meter calibration base was established in the vicinity of Sperryville, Va. This new base, consisting of two stations having a gravity difference of about 74 milligals, provides better calibration data than the longer base previously employed.

Beginning in November 1958 a gravity base traverse was run between Bellingham, Wash., and San Diego, Calif., comprising 68 primary stations and numerous auxiliary points established for convenience in future recovery. The traverse was connected to the mid-continent gravity base by direct air transport over the lines: Seattle, Wash., to Fargo, N. Dak.; San Francisco, Calif., to Kansas City, Mo.; and San Diego, Calif., to Dallas, Tex. Improved gravity values were determined for 51 pendulum stations along the west coast.

A special gravity survey was completed at Vandenberg Air Force Base and the U.S. Navy Missile Facility near Pt. Arguello, Calif., in connection with rocket launching requirements. About 140 stations were established at a rectangular spacing of approximately 3 miles.

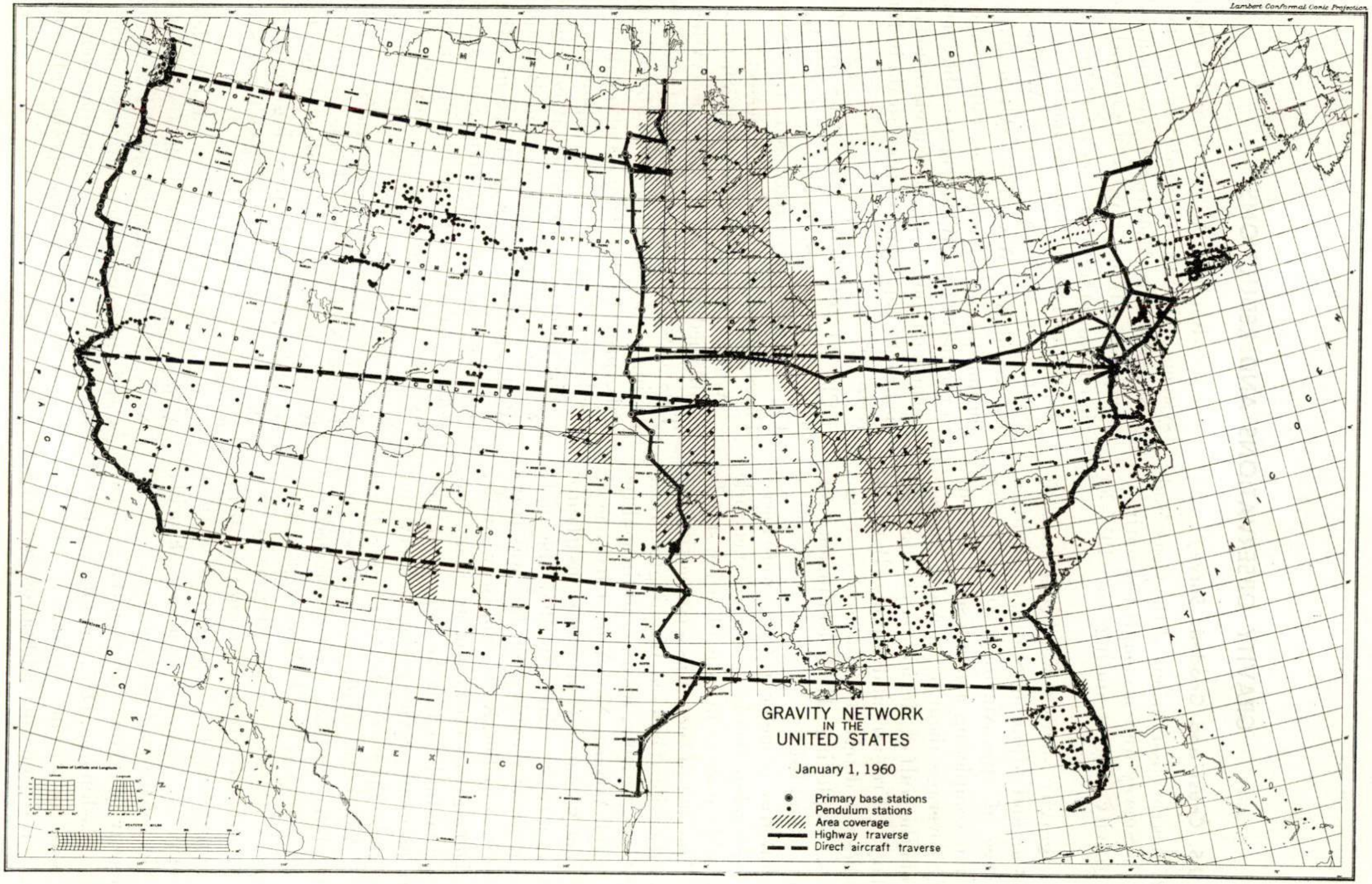

FIGURE 17.—Gravity network of the Coast and Geodetic Survey.

Lambert Zenithal Equal Area Projection

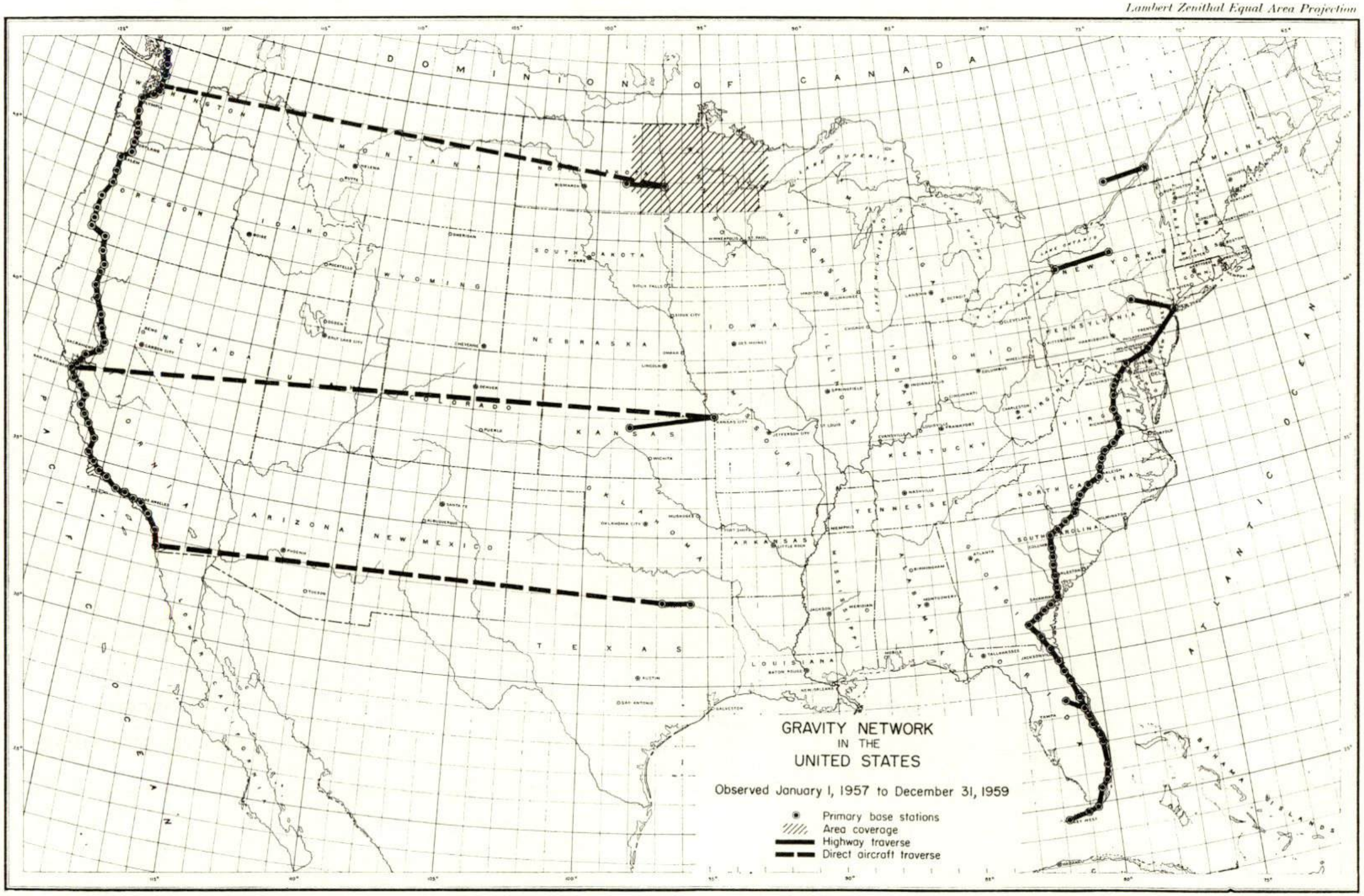

FIGURE 18.—Extension of gravimetric observations by the Coast and Geodetic Survey.

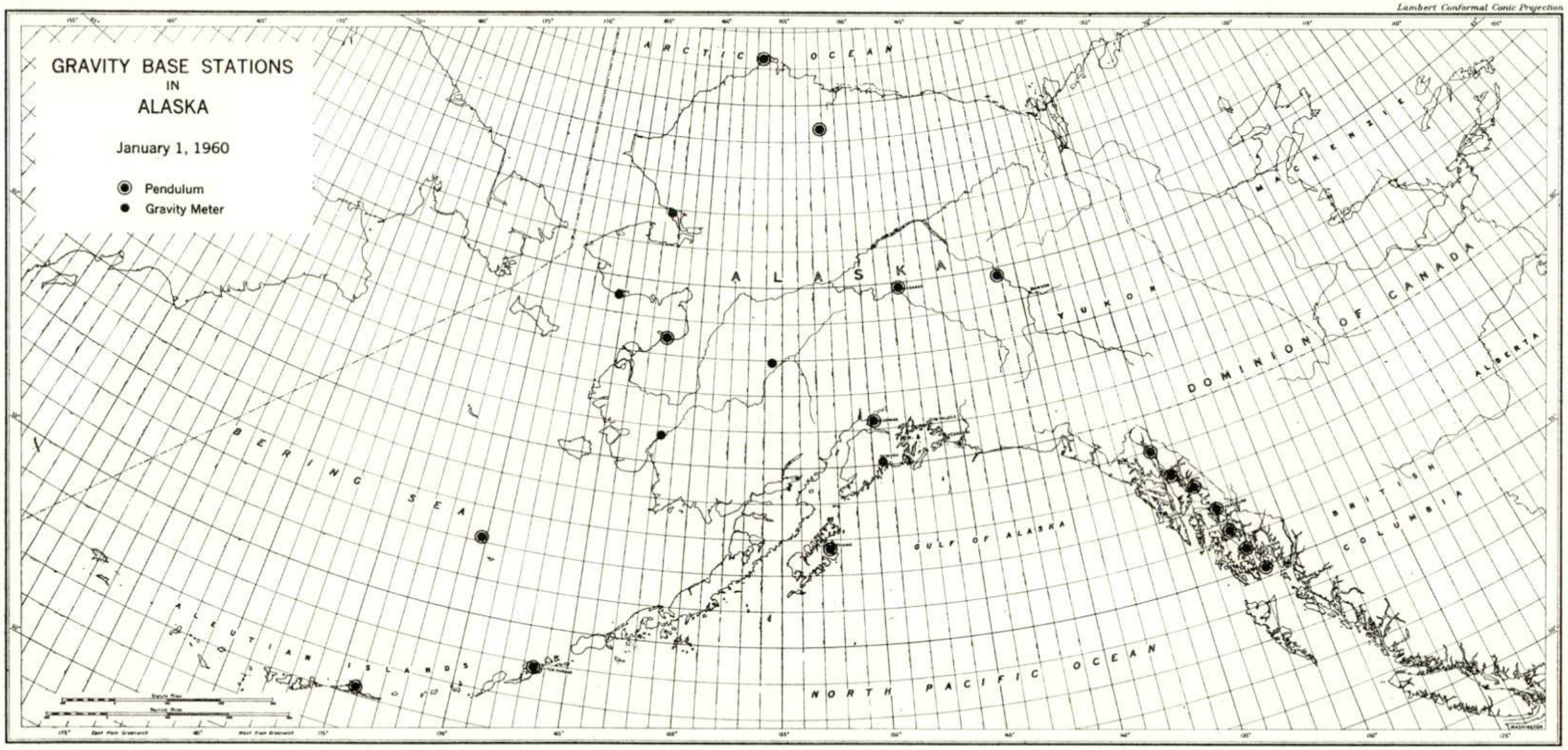

FIGURE 19.—Coast and Geodetic Survey gravity base stations in Alaska.

U.S. Geological Survey

Regional gravity surveys in parts of 18 States have been conducted by the Geological Survey in connection with geologic investigations. Emphasis has been placed on areas in Pacific Northwest, Maine, and Alaska, where natural resources are relatively undeveloped. Gravity measurements were also made in Nevada, eastern California, southeastern Utah, northern New Mexico, eastern Kentucky, and the Black Hills of South Dakota. About 23,000 gravity stations were occupied during 1957–59 in these various areas, which total about 210,000 square miles. The station spacing varies from one-half mile for semidetailed investigations to as much as 7 miles for regional work. These data are being used primarily to locate and trace geologic structures at depth and to obtain information on the major rock masses.

All gravity observations have been tied to Dr. G. P. Woollard's airport network in the United States or to U.S. Coast and Geodetic Survey pendulum stations. Standard Bouguer reductions for an assumed density of 2.67 g. per cc. have been made for all stations and many stations have been reduced for several additional densities which apply to local areas. The Bouguer reductions include curvature and terrain corrections through Hayford Zone "O" in areas where these corrections are significant to the interpretation of local anomalies. Airy-Heiskanen (T=30 km.) anomalies have been computed for about 150 stations in east-central California in connection with a study of the Sierra Nevada Mountains.

The computations of free-air and Bouguer anomalies including curvature and terrain corrections have been programmed for the Geological Survey's Datatron equipment and the program has been in operation since August 1, 1959.

The Geological Survey has agreed to publish and distribute free-air and Bouguer gravity maps of the United States in cooperation with the American Geophysical Union's "Committee for the Geological and Geophysical Study of the Continents." The gravity maps are being compiled by a group of editors under the direction of Dr. Woollard.

U.S. Army Map Service

In July 1959 the U.S. Army Map Service obtained two LaCoste-Romberg model-G gravity meters, which have been used on field projects in Iran, Greenland, Taiwan, and the Ryukyus.

Inter-American Geodetic Survey

The Inter-American Geodetic Survey has cooperated in establishing approximately 12,000 gravity stations in Mexico and Central and South America.

Gravity traverses along main first-order level lines have been completed from Santiago, Chile, to northern Colombia, and along the transcontinental level line from Arica, Chile, to Rio de Janeiro, Brazil. Free-air anomalies have been compiled for the observations in Chile, Bolivia, and Ecuador.

A gravity survey along existing level lines in the Dominican Republic has been completed and free-air anomalies compiled.

The gravity coverage of the La Canoa Datum in Venezuela has been systematically extended to a radius of about 130 kilometers. An extensive area of large negative free-air anomalies extending from Trinidad to central Venezuela has been discovered.

Cooperative surveys for general gravity coverage are being continued in Brazil, Bolivia, Peru, Colombia, Venezuela, Honduras, Guatemala, British Honduras, Mexico, Cuba, and Jamaica.

U.S. Air Force

Under sponsorship of Air Force Cambridge Research Center the group under Dr. G. P. Woollard carried out observations with the Gulf quartz pendulums (M set) throughout Alaska, South America, the Far East, Australasia, and Antarctica. Approximately 30 new stations were occupied.

In order to provide an interim system of nationwide bases for control of gravity surveys, the Air Force Cambridge Research Center sponsored the establishment of a network of approximately 130 gravity stations at airports throughout the United States. Measurements were made with two high-range Worden meters by the University of Wisconsin group under Dr. Woollard. Recovery of many of these airport stations in the Coast and Geodetic Survey base net program indicates an average agreement of 0.3 milligal.

Under sponsorship of Air Force Cambridge Research Center, the group under Dr. Woollard completed in 1958 a series of gravity meter observations in Alaska primarily to extend the coverage of gravity bases. The work comprised observations at 513 sites of which approximately one-third are located at airports and the remainder are located on traverses at a 5- to 10-mile station spacing.

The first known measurements of gravity in a flying aircraft were made in a test conducted by Air Force Cambridge Research Center on November 6 and 7, 1958, at Edwards Air Force Base, Calif. A LaCoste-Romberg surface ship gravity meter was mounted in a KC–135 jet tanker and flights were made in north, south, and west directions at altitudes of 20,000 and 30,000 feet. Navigational data were provided by a Doppler system in the aircraft, and ground tracking facilities. In this initial test accuracy of the order of ten milligals was indicated by comparison with gravity extrapolated from the ground surface.

A joint U.S. Air Force—Inter-American Geodetic Survey effort established a gravity reference station network throughout the project area of the Cuba—Central American Survey as indicated in figure 16. All the stations are tied to the international pendulum station located at Albrook AFB, Canal Zone. Gravity meters were used to measure at least two gravity differences between each two successive reference stations of the network loops. Preliminary computations indicate loop closures of less than 0.2 mgal; however, final computations and adjustments have not been completed at the time of this report. IAGS personnel acquired additional detail data in the vicinity of each station.

Other Organizations

The Institute of Geophysics, University of California at Los Angeles, reports very favorable comparative tests of the LaCoste-Romberg surface ship meter with 14 previously established submarine stations off southern California, and with 27 underwater meter stations. The surface ship meter has also been employed recently in a survey of the Gulf of California in which continuous profiles across the Gulf were established at 10-mile intervals.

Recent sea gravity activities of the Columbia University group under J. L. Worzel include measurements on H.M.S. *Telemachus* at 130 stations in the vicinity of Australia and New Zealand in 1956; on U.S.S. *Grenadier* (SS *525*) at 29 stations in the western Atlantic; and surface ship measurements taken on U.S.S. *Compass Island* along a track from New York through the Straits of Gibraltar to the western Mediterranean. Other extensive tests on surface ship gravity measurements were carried out by this group.

Under the IGY Antarctic program gravity bases were established at 11 stations, the network being controlled by pendulum ties from McMurdo to Christchurch and Melbourne, and by gravity meter ties from Ellsworth to the pendulum stations at Buenos Aires and Punta Arenas, South America. Approximately 4,100 miles of gravity traverse were run, with stations spaced at 5- to 15-mile intervals. Gravity data from the program are being processed by the Antarctic Gravity and Seismological Data Reduction Center at the University of Wisconsin.

The Woollard group continued its worldwide program of gravity meter observations. New work included ties between the various

U.S. Antarctic bases and connections to the British Base (Fuchs party), New Zealand Base (Hallett), and Russian Base (Mirny). Numerous observations were made in Central and South America, in Australia, and along the areas of pendulum operations.

GEOID INVESTIGATIONS

U.S. Coast and Geodetic Survey

In 1956 work was begun on the determination of a precise geoid profile extending over the total width of the United States along the 35th parallel. Astro-geodetic stations were established at an average spacing of about 14 miles. Second-order astronomic positions were determined at each station, supplemented by first-order positions at intervals of four or five stations to provide frequent checks of observer personal equation. The methods employed gave an accuracy of slightly better than one second of arc in the prime-vertical deflections, which are critical in construction of the profile. At the end of 1959, 147 stations had been determined over the section of approximately 2,100 miles extending from the Atlantic Ocean to central Arizona. The profile will be completed early in 1960 by the addition of 30 more stations in Arizona and California. A preliminary study has been made of the available data based on the Clarke Spheroid of 1866, North American 1927 datum. From an assumed geoid height of zero at the Atlantic coast, the geoid rises gradually to a maximum of 12 meters in western Tennessee, drops gradually, then undulates moderately over a range of plus one to plus six meters until the line reaches western New Mexico. From this point the geoid drops to about minus four meters in central Arizona.

The problem of determining anomalous components of the earth's gravity field at altitudes of several hundred miles was investigated, working procedures developed, and values determined for various typical rocket trajectories. The analysis was based on the Stokes surface coating as derived from sea level gravity anomalies and geoid height data.

A geodetic datum position was determined for Ascension Island, based on first-order astronomic positions and gravimetric deflections of the vertical at three stations on the island.

U.S. Army Map Service

The U.S. Army Map Service extended its computation of geoid heights by astro-geodetic data into India, Japan and Korea, around the Caribbean, and into Brazil, to cover the areas shown in figure 20.

A statistical and harmonic analysis of free-air gravity anomalies and topography was made. Markov analysis was applied to obtain a worldwide estimate of gravity, and autocorrelation analysis was applied to obtain errors of representation in both gravimetric and astro-geodetic data.

Secular motions of the node and perigee of the Vanguard I satellite were analyzed to obtain a new estimate of the flattening: 1/298.3.

The astro-geodetic geoid, worldwide gravity anomaly estimates, secular and long-period motions of the Vanguard I satellite (as analyzed by the National Aeronautics and Space Administration) and the North Atlantic HIRAN survey connection (observed by the U.S. Air Force) were combined in a generalization of least squares applicable to correlated data to obtain: shifts for the North American, European, and Tokyo Datums; ellipsoid and standard gravity formula parameters; and an expression of the geoid in spherical harmonics to the eighth degree. The standard deviations obtained were ± 8 meters in equatorial radius, ± 0.01 in the reciprocal of flattening, ± 0.001 cm/sec^2 in equatorial gravity, ± 25 meters (spherical) for the European Datum, ± 27 meters for the North American Datum, and ± 62 meters for the Tokyo Datum.

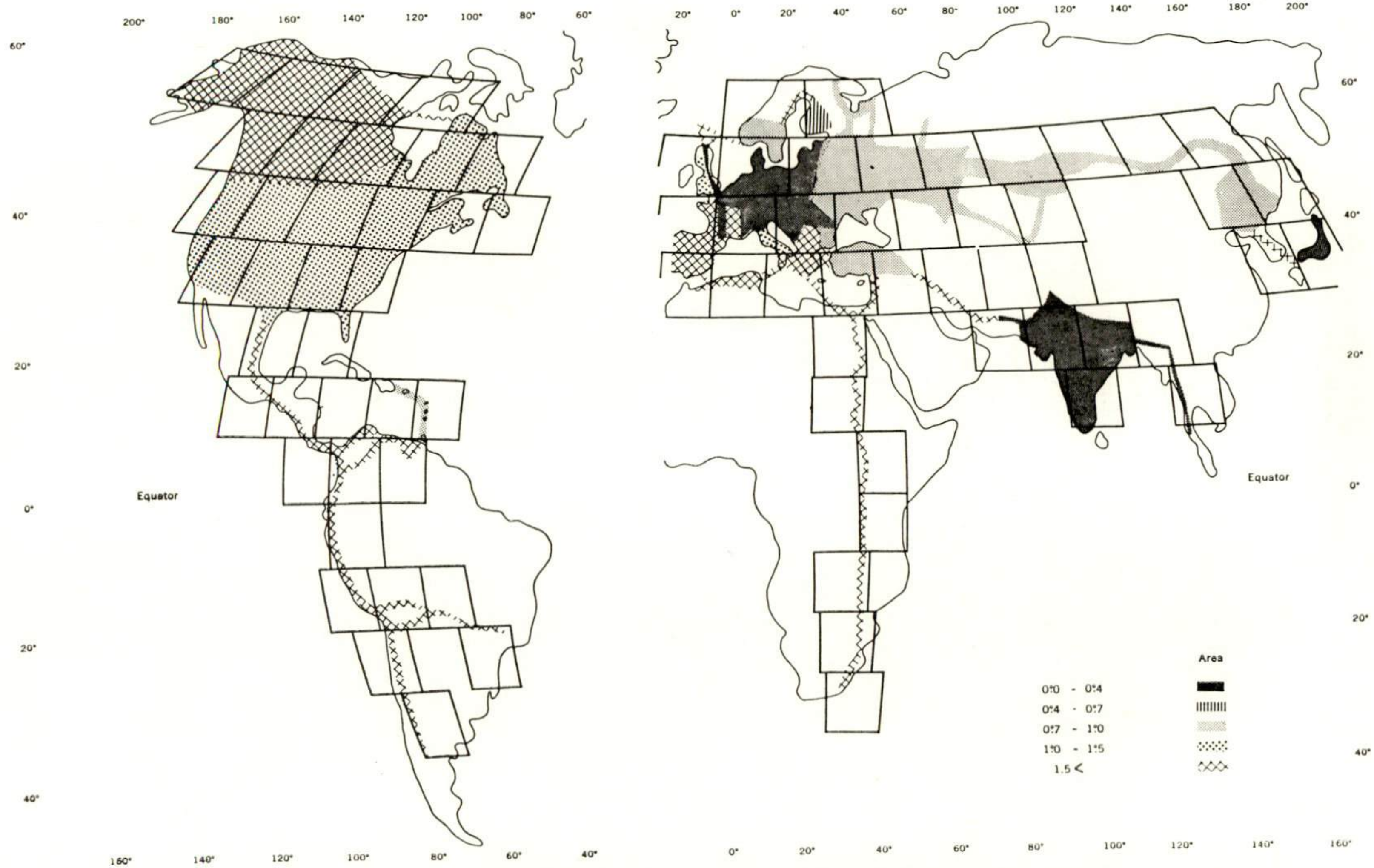

FIGURE 20.—Astronomic-geodetic station spacing.

U.S. Air Force

In 1957 the U.S. Air Force contracted for the computations of gravimetric deflection components and geoid heights at 35 selected first-order astro-geodetic stations; 11 in the United States, 13 in Europe, 8 in Japan, and 3 in Manchuria. Available worldwide gravity coverage was used and the computations were based on free-air anomalies computed by the use of the International Gravity Formula. Zero free-air anomalies were assumed for the gravimetrically unsurveyed sea areas. In 1959 these gravimetric quantities were recomputed on the basis of a different gravity formula with a changed flattening term and under the assumption of zero isostatic anomalies for the gravimetrically unsurveyed areas.

Gravimetric quantities available were utilized in an attempt to unify the geodetic datums of the different continents. The first reduction of the European, North American, and Tokyo Datums into a common earth-centered geodetic system was accomplished in March 1958 and another attempt to improve the "World Geodetic System" was published in August 1959. The USAF 1959 solution, together with the work accomplished by the Army Map Service, constitutes the Department of Defense World Geodetic System which will be adopted in 1960.

OTHER ACTIVITIES

U.S. Air Force

In cooperation with the British Air Ministry and the Military Survey, a composite USAF–USC&GS team accomplished limited geodetic surveys in England from April 1958 through June 1959. Surveys for the THOR program were carried out in Lincoln, Norfolk, Cambridge, and Suffolk Counties. The THOR program subsequent to June 1959 is being carried on by the British Air Ministry and Military Survey.

USAF missile survey requirements in the United States were assigned to USC&GS for accomplishment.

MISCELLANEOUS NOTES

Important Geodetic Meetings, 1957–1959

During the period of this report, several important meetings of geodesists were held in the United States, among these the more important are listed with the places, dates, and sponsorships.

CAMBRIDGE, MASS., DECEMBER 1–2, 1958

A Conference on Contemporary Geodesy was sponsored by the Section of Geodesy, American Geophysical Union, in cooperation with the Harvard University and Smithsonian Astrophysical Observatory. The Proceedings of this conference were published as Monograph No. 4 of the American Geophysical Union.

BEDFORD, MASS., DECEMBER 3–4, 1958

A Seminar on Military Geodesy was sponsored by the U.S. Air Force, Cambridge Research Center.

WASHINGTON, D.C., MAY 5–12, 1959

A Symposium on Electronic Distance-Measuring Equipment was sponsored by the International Association of Geodesy at which the Section of Geodesy, American Geophysical Union, was host.

WASHINGTON, D.C., AUGUST 6–7, 1959

A Conference on Military Requirements for Geodesy was sponsored by the U.S. Army Map Service.

American Geophysical Union Committee on Geodetic Applications of Artificial Satellites

Because of interest shown in some of the discussions at the 11th General Assembly of the I.U.G.G. (Toronto 1957), an informal committee was organized within the Section of Geodesy, A.G.U., for the purpose of studying geodetic applications of artificial satellites. The committee has served primarily for the exchange of ideas and opinions rather than as a policymaking or advisory group.

A preliminary meeting was held at the Army Map Service in December 1957, at which time the broad aspects of the geodetic satellite program were discussed. The next meeting of the group was in Boston in March 1958 at the invitation of the Air Force Cambridge Research Center. Later that year in May at the time of the annual meeting of the A.G.U., several members of the committee met again. A summary report was prepared after that May meeting so that printed material might be available for submission to agencies or individuals interested in the geodetic satellite program.

When the Panel on Geodesy, under the Space Science Board, was organized, several members of this A.G.U. committee were asked to serve. The committee itself, because of its informal organization, has not met regularly but the individuals who participated in these earlier meetings continue to exchange ideas either by correspondence or in small group discussions.

The basic concepts developed within this group for a geodetic satellite program were forwarded to the National Aeronautics and Space Administration and are being used by that agency in the development of its program.

Personalia

The following personalia covering the period of this report will be of interest to those affiliated with the International Association of Geodesy:

Capt. Charles Pierce, formerly Chief, Geodesy Division, U.S. Coast and Geodetic Survey, moved up as Assistant Director of that organization with the rank of Rear Admiral in August 1957. He was succeeded by Capt. John H. Brittain.

Mr. D. L. Parkhurst, for many years Chief, Instruments Division, U.S. Coast and Geodetic Survey, retired in July 1959 and passed away suddenly in October of the same year.

Col. Floyd W. Hough, Chief, Department of Geodesy, U.S. Army Map Service, retired in February 1957 and was succeeded by his principal assistant, Mr. David L. Mills.

Mr. Frank L. Culley, Deputy Secretary, for the American Countries, of the International Association of Geodesy, transferred from the U.S. Coast and Geodetic Survey to the U.S. Army Map Service in February 1957, where he took up the duties of Assistant Chief, Department of Geodesy.

Dr. John A. O'Keefe, formerly Chief, Research and Analysis Division, Department of Geodesy, U.S. Army Map Service, transferred to the National Aeronautics and Space Administration in November 1958. He was succeeded at the Army Map Service by Mr. William M. Kaula.

Mr. Gunnar Leifson, long-time Head of the Survey Branch, U.S. Navy Hydrographic Office, retired in April 1959. He was replaced by Mr. M. R. Ullom.

Mr. Ronald M. Wilson who was for many years the leading geodesist of the U.S. Geological Survey, and as such was responsible for many technological advances before his retirement on October 31, 1956, died on November 28, 1959.

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