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GEODETIC OPERATIONS IN THE UNITED STATES JANUARY 1, 1927, TO DECEMBER 31, 1929

{ Report to the Section of Geodesy of the International Geodetic and Geophysical Union, International Research Council }

BY

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GEODETIC OPERATIONS IN THE UNITED STATES, JANUARY 1, 1927, TO DECEMBER 31, 1929

By WILLIAM BOWIE, *Chief, Division of Geodesy, United States Coast and Geodetic Survey, Washington, D. C.*

GENERAL STATEMENT

This is one of the series of reports on geodetic work accomplished in the United States which have been made to the International Geodetic Association and, since the World War, to the section of geodesy of the International Geodetic and Geophysical Union. These reports are not designed to give in great detail an account of the work accomplished or that in progress at the time of their preparation. They do, however, give sufficient information to enable the reader to form a fairly clear picture of accomplishments in the field of geodesy in the United States during the period covered.

Most of the geodetic work in the United States is done by the United States Coast and Geodetic Survey, a bureau of the Federal Government, which is charged by law with the execution of triangulation and leveling, the determination of latitude and longitude by astronomical observations, and the determination of gravity over the United States and its outlying areas. The bureau is also charged with the duty of making observations for the variation of latitude at the station at Ukiah, Calif.

Along the coasts of the United States and its outlying areas the United States Coast and Geodetic Survey executes detailed triangulation for the immediate control of hydrographic and topographic surveys used in making nautical charts. The control surveys over continental United States and those to be done in the interior of Alaska consist of first and second order triangulation and leveling. These control surveys are designed to furnish the framework or basis for topographic mapping, for the location of political boundaries, and for the detailed surveys required in many engineering operations. The data are also used in scientific studies such as the determination of the figure of the earth, studies of the deflections of the vertical and isostasy, and investigations of the movements of the earth's surface in regions of seismic activity.

The plan followed by the Coast and Geodetic Survey for these control surveys is to have the arcs of triangulation and lines of levels spaced in such a way that few places in the country will be at a greater distance than about 25 miles from a triangulation station or a leveling bench mark determined with first or second order accuracy.

Some geodetic work has been done in this country in the laboratory or office as well as in the field. Reports on some of these projects showing the results accomplished are given by statements in this publication which appear under the names of the officials who prepared the statements in question.

The first part of this report gives in abstract form an account of the work accomplished in several lines of geodetic work. The latter part covers in somewhat greater detail the operations by the Coast and Geodetic Survey and other organizations for which there are at present no published accounts.

READJUSTMENT OF TRIANGULATION NET, WESTERN UNITED STATES

A brief account of this adjustment is given in Special Publication No. 134, the report on geodetic work in this country presented three years ago. A publication by Dr. O. S. Adams, in charge of the adjustment, has recently appeared as Special Publication No. 159, entitled "The Bowie Method of Triangulation Adjustment."

For the benefit of those who are not familiar with this work it should be stated that the adjustment involved 13,000 miles of arcs of first-order triangulation, with 16 closed loops. There were 50 base lines in the net and 74 Laplace azimuths.

During the past three years the geographic positions of all intersection points have been fitted to the adjusted main scheme of the triangulation. It is hoped that within a short time it will be possible to publish the results of the triangulation data for each of the States covered by this net. The first one of these State publications giving results on the new datum will be issued early in 1930. It is Special Publication No. 160, entitled "Triangulation in Colorado (1927 Datum)."

SOUTHEAST ALASKA ON NEW DATUM

The new datum established by the readjustment described above has been carried into southeast Alaska. This was accomplished by a cooperative agreement with the Geodetic Survey of Canada who carried the datum from northwest Washington to Dixon Entrance, through an arc of first-order triangulation along the Pacific coast. A discussion by Walter F. Reynolds of the triangulation computation of southeast Alaska will be found on page 17.

READJUSTMENT OF TRIANGULATION NET, EASTERN UNITED STATES

The method used in the readjustment of the triangulation of the western part of the United States proved so satisfactory and successful that the officials of the Coast and Geodetic Survey decided to make a readjustment of the triangulation net covering the eastern part of the country. Already most of the field work necessary to complete the main part of the net has been done. There remain to be executed about 2,000 miles of arcs of first-order triangulation, shown by shaded bands on Figure 4. It is expected that this additional triangulation will be finished by June, 1931. In addition to the triangulation some base measurements and Laplace azimuths are needed to furnish the necessary data to control the lengths and azimuths in the adjustment. It is expected that these will be available by the time the triangulation has been finished.

Already computations have been begun for this adjustment of the eastern net. The first step in the adjustment is the formation of equations by which the most probable length and azimuth of a line at each junction point of the net may be obtained.

It is expected that the eastern net will comprise 13,000 miles (21,000 kilometers) of arcs of first-order triangulation which will form 30 closed loops. The computations will be pushed forward as rapidly as the field work necessary to supplement the existing data can be finished. Doctor Adams, who was in charge of the readjustment of the triangulation net of the western part of the country, will also be in charge of the readjustment of the eastern portion.

FIRST-ORDER TRIANGULATION

Since January 1, 1927, there have been executed in the United States 3,040 miles of arcs of first-order triangulation. These arcs are shown in red on Figure 1. The practice has been followed of using quadrilateral or central-point figures except in rare cases where it was impossible to observe the diagonal line because of obstructions which would have required extensions to the towers already erected. In such cases a short portion of the arc consisted of single triangles.

NUMBER OF OBSERVATIONS

The practice has been followed for many years and continued during the past three years of making two observations on each line of the main scheme of first-order triangulation in each of 16 positions of the horizontal circle. Thus 32 pointings are made over each line radiating from a station. The mean of these observations is used to derive the direction of a line. If any line is not observed in one of the regular settings of the circle then it is subsequently observed

TRIANGULATION

U.S. Coast and Geodetic Survey

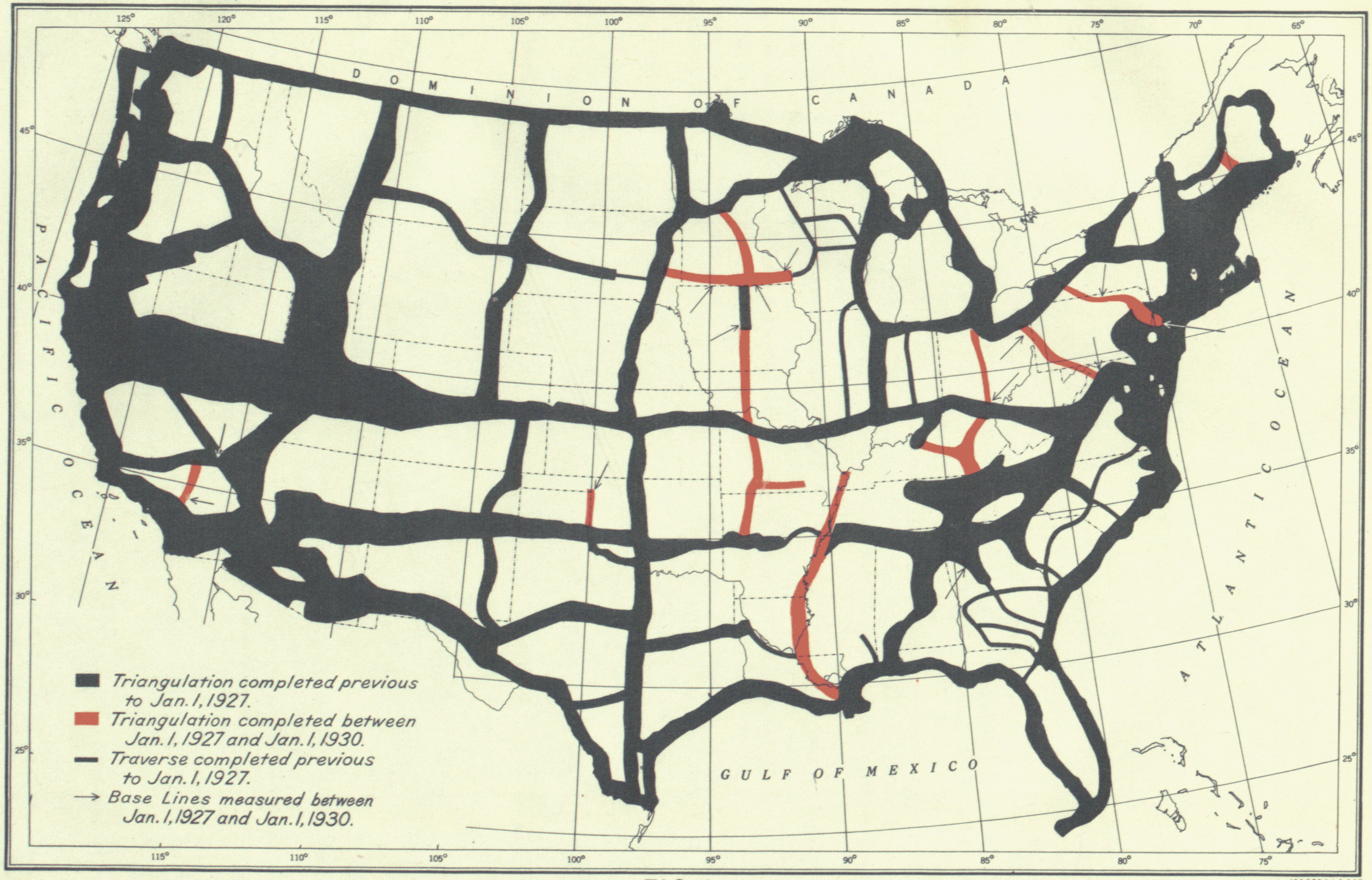


FIG. I

by connecting it with some previously observed line using the same position of the circle. By following this method, no conditions enter into the observations at a station and, in consequence, the computations for deriving the values of the directions are very simple and short.

CLOSING ERRORS OF TRIANGLES

The average closing error of the triangles for an arc in the first-order net of the country seldom exceeds 1″. The closing error, as is well known, is the difference between the sum of the three observed angles of the triangle and 180° plus the spherical excess of the triangle. No effort is made to secure an average closing error smaller than 1″ unless this can be done with very little extra expenditure of time and money. The observer is encouraged to study atmospheric conditions and the character and appearance of lights on which he makes his pointings with a view to obtaining closing errors within the limit.

Some notable instances of rapid and accurate observing have occurred. In 1928 two observing parties working under one chief of party completed a triangulation from central Iowa southward into central Arkansas along the ninety-third meridian. This party was under the direction of Earl O. Heaton, with Joseph M. Smook and later Ralph L. Pfau in immediate charge of the second observing unit. The observations for this arc began on June 14 and ended on September 28 or covered a period of 107 days between the first and last observations. The arc is 590 miles (950 kilometers) in length, and there are 96 stations in the main scheme each of which was occupied for horizontal angle observations.

In nearly all cases the observations at a station were made during a single night, and it was only occasionally that they required more than three hours. When the atmosphere was clear and the lights fairly steady the observations were finished in slightly less than two hours. The average closing error of the triangles was 0″.86.

This triangulation party made the observations for Laplace azimuth at intervals of approximately 100 miles along the arc and observed additional azimuths between the Laplace stations. For each Laplace azimuth, observations were usually made on Polaris on two nights. (See statement under Field Astronomy, p. 6.)

On July 30, 1929, observations were begun on an arc of triangulation extending along the Mississippi River from Cairo, Ill., to New Orleans, La. The last observation on this arc was made on January 31, 1930. The length of this arc along its main axis is 595 miles, and 185 stations were occupied. The average closing error of the triangles was 0″.89. This was a very notable piece of work because of the many difficulties encountered. The area is very flat and is partly covered by forests which, in many places, have trees as high as 125 feet. It was necessary to elevate the instrument and the signal lamp to such heights as to make it possible to see over the trees and to overcome the effect of the curvature of the earth. The average rate of progress for a 30-day month on this arc was 96 miles (154 kilometers). On the ninety-third meridian arc mentioned above the corresponding progress was 165 miles (266 kilometers).

INSTRUMENTS USED

A variety of instruments has been used recently on first-order triangulation. They include the 12-inch direction theodolite, Coast and Geodetic Survey model, which has been used very extensively by the bureau during the past 35 years, the 9-inch Hildebrand direction theodolite, the Kern 9-inch direction theodolite, and the Parkhurst 9-inch direction theodolite. The dimensions, of course, refer to the diameter of the horizontal circle of the instrument. The general consensus of opinion now is that the required degree of accuracy can be obtained with a reasonable number of observations made with a 9-inch direction theodolite. This size of instrument is much more convenient because of its smaller bulk and weight which make it much easier to transport in the field than the larger 12-inch theodolite.

Electric signal lamps have been used exclusively as marks on the first-order triangulation, the observations being made entirely at night. These lamps have been described in publications of the Coast and Geodetic Survey which can be consulted by the reader. (See Coast and Geodetic Survey Special Publication No. 120, Manual of First-Order Triangulation.)

PARKHURST THEODOLITE

The Parkhurst 9-inch direction theodolite previously mentioned was designed by D. L. Parkhurst, chief of the instrument division of the Coast and Geodetic Survey, and was constructed in the shops of that division under his direction. The actual mechanical work was done by A. Heim, instrument maker. The instrument combines the good features of existing theodolites with some new devices especially designed by Mr. Parkhurst. It is described in an article by Mr. Parkhurst which appeared in the Journal of the Franklin Institute October, 1928, and in the Engineering News-Record November 29, 1928.

Briefly, its new features are first a double cone vertical axis with the apices of the two truncated cones coinciding. The lower cone has a wide angle, and its chief function is to support the weight of the alidade; while the upper cone has a narrow angle, and its function is to hold the axis vertical. By having the apices of the two truncated cones coincide, binding due to changes in temperature is eliminated. Tests show that the instrument has very free motion in azimuth at both high and low temperatures.

The clamping device is mounted on ball bearings which insure easy motion. It consists of a block which is pushed in or drawn out by a radial thumbscrew and this prevents binding when the clamp is released. There is also a new type slow-motion screw for the movement of the tangent arm. This screw operates a sleeve which does not rotate and therefore has no tendency to tilt the alidade when the screw is turned. The micrometer is fitted with a head made of clouded glass, white in color, on which are the graduations to give the seconds readings. The index line is also on a piece of clouded glass. A small electric bulb inside of the glass ring furnishes very effective illumination when the micrometer is used at night.

The circles of the Parkhurst theodolite were graduated by the Fennel Co. of Cassell, Germany. The Parkhurst theodolite has been successfully used in the field. It is rapid in operation and gives results of high-grade accuracy.

Mr. Parkhurst has recently designed a direction theodolite with a 6½-inch circle for use in second and third order triangulation. This instrument is similar to the 9-inch theodolite except that the micrometer box is fitted with ball bearings which support the frame carrying the cross wires. This insures very smooth movement of the micrometer screw and prevents any material difference of the micrometer readings depending on whether the motion is against the spring or with it. This is a matter of considerable importance because time is saved in making the readings of the circle if it is unnecessary to always work the micrometer screw against the spring. This small instrument was also made in the shops of the instrument division, the mechanical work also having been done by A. Heim. At the time this report was being prepared this small instrument was in the field for testing. No report on the results obtained with it is yet available.

PARKHURST VERTICAL COLLIMATOR

A new type of vertical collimator for centering an instrument over a point on the ground has been designed by Mr. Parkhurst and has been constructed in the shops of the bureau. It has proved to be entirely satisfactory, and it is now the standard instrument of its kind in the work of this bureau. The instrument can be mounted on a tripod and is used to project a vertical line upward. A description of the instrument and the manner of using it is given on page 17 of Special Publication No. 158. See also page 70 of Special Publication No. 145.

BILBY STEEL TOWER

Beginning with the season of 1927 the Coast and Geodetic Survey has used the Bilby steel tower on its triangulation in areas where towers are required because the country is comparatively level or forests make it impossible to observe the lines of triangulation without cutting many trees. Prior to 1927 wooden towers had been in use for this purpose but, owing to the higher cost of lumber since the World War and also to the increased salaries and wages paid to personnel, the cost of triangulation with wooden towers became so high that, in several instances, traverse was substituted for triangulation. While traverse is quite effective in extending horizontal control over flat areas it covers only a line while triangulation covers an area. The problem of the tower was solved when Jasper S. Bilby, chief signalman of the Coast and Geodetic Survey, designed a steel tower which could be easily erected and could be taken down and used at other stations. After he had made his preliminary design, which showed that the tower was feasible and gave promise of being satisfactory, engineers of the Aermotor Co., of Chicago, Ill., made a finished design and then constructed a tower which was given a very severe test for strength and rigidity. When these tests proved that the tower was entirely satisfactory a sufficient number of additional towers were purchased for the use of the triangulation party in Minnesota in 1927, and since that time they have superseded the wooden towers. The Bilby steel tower is described in detail in Coast and Geodetic Survey Special Publication No. 158, entitled "Bilby Steel Tower for Triangulation."

The tower was originally 77 feet high to the top of the inner tripod and 87 feet to the top of the outer one. It can be increased in height by the addition of lower sections. In the triangulation along the Mississippi River, during the season of 1929, the Bilby tower was increased in height to 129 feet to the top of the inner structure. Where a very low tower is needed, only the top sections of the tower are erected. These towers can be reerected many times, as is indicated by the fact that some of them have already been erected at 30 or more triangulation stations. They are still in excellent condition and can probably be used at an additional 50 or 100 stations. As a matter of fact, there is no apparent limit to the number of stations at which one of these towers can be used. If one of the members of the tower is injured it can be repaired or replaced.

STATISTICAL DATA FOR TRIANGULATION EXECUTED

There is given below a table showing the various arcs of triangulation which have been executed in the United States during the period covered by this report.

Arcs of first-order triangulation

[January 1, 1927, to December 31, 1929]

	Miles
City of Atlanta, Ga., E. O. Heaton, 1927	25
Ninety-eighth meridian to La Crosse, South Dakota and Minnesota, and Albert Lea to Royalton, Minn., H. W. Hemple, 1927	460
Pittsburgh arc, Maryland, Virginia, West Virginia, Pennsylvania, and Ohio, W. Mussetter, 1927–28	260
One hundredth meridian, Oklahoma and Texas, W. Mussetter, 1927	115
Ninety-third meridian, Iowa, Missouri, and Arkansas, E. O. Heaton, 1928	495
Springfield to Van Buren, Mo., E. O. Heaton, 1928	95
Kentucky arc, H. W. Hemple and W. Mussetter, 1928	235
Augusta to international boundary, Maine, C. A. Schanck, 1928–29	85
Columbus arc, Ohio, W. Mussetter, 1928, and C. M. Thomas, 1929	225
Buffalo-Trenton arc, New York, Pennsylvania, and New Jersey, C. M. Thomas, 1929	300
Mississippi River arc, Illinois, Missouri, Kentucky, Arkansas, Tennessee, Mississippi, and Louisiana, H. W. Hemple, 1929	595
Newport Beach to thirty-fifth parallel, California, G. L. Bean, 1929	150
Total	3,040

First-order traverse

City of Atlanta, E. O. Heaton, 1927	55
Wright Field, Dayton, Ohio, C. M. Durgin, 1927	63
Total	118

SPECIAL TRIANGULATION AND LEVELING IN CALIFORNIA

For several years the Coast and Geodetic Survey has been executing triangulation and leveling in California to serve as a basis for determinations of the extent to which the earth's surface moves horizontally and vertically at the time of an earthquake. The results will also be valuable in the determination of movements that may occur even though there may be no earthquake in the region. If the triangulation and the leveling observations are repeated after an interval of years or immediately after the occurrence of a large earthquake, accurate measurements of the horizontal and vertical movements will be available.

Detailed information regarding changes in geographic positions of the first-order triangulation extending from central Nevada westward to the Pacific coast in the vicinity of San Francisco, thence southward nearly to the Mexican boundary, thence eastward into Arizona, is contained in Coast and Geodetic Survéy Special Publication No. 151, entitled "Comparison of Old and New Triangulation in California." The original observing on this triangulation was done prior to 1900, except at a few stations at the southern end of the area under consideration. The new observations were made during the years 1923 to 1926. Anyone interested in this work should secure a copy of the publication referred to above.

An additional arc of first-order triangulation has been extended from Newport Beach, in southern California, northeastward to Lucerne Valley, thence northward to the triangulation running eastward across California. Along a greater portion of this arc many intermediate stations were established in order to have a close grouping of stations in or very close to fault zones. These intermediate stations were located by the methods of second-order triangulation. The main scheme is, however, of first-order accuracy.

Another arc on which some work has been done extends eastward from Point Reyes, which is on the California coast just north of San Francisco. This arc will extend inland for about 150 miles. The same methods will be used on it that were employed on the arc in southern California just described.

This triangulation, and also some leveling in California, are designed to disclose earth movements in regions of seismic activity, and are being executed in cooperation with the advisory committee in seismology of the Carnegie Institution of Washington. Dr. Arthur L. Day, director of the geophysical laboratory of the Carnegie Institution of Washington, is the chairman of that committee.

ASTRONOMICAL WORK

The astronomical work of the United States, which is of particular value to the geodesist, consists of the determination of longitudes, latitudes, and azimuths at triangulation stations; the determination of time and the sending of time signals by the United States Naval Observatory used in longitude and gravity work; and the observations for variation of latitude made at the United States Naval Observatory in Washington, D. C., and at Ukiah, Calif.

FIELD ASTRONOMY

The purpose of longitude and azimuth determinations at triangulation stations is primarily to furnish Laplace azimuths for controlling the directions of lines of the triangulation net. Laplace azimuths have been found most effective in the adjustment of triangulation and are extensively used in the United States. As is well known, a Laplace azimuth is an observed astronomical azimuth corrected for the deflection of the vertical at the point of observation. The deflection is obtained by a comparison of the astronomical and geodetic longitudes at the point. The astronomical longitudes are also useful in furnishing data for redeterminations of the figure of the earth and for isostatic studies. Usually an astronomical latitude is also determined at the place where the longitude and azimuth are observed. The latitude determination is not needed in the derivation of the Laplace azimuth, but when it is compared with the geodetic latitude it furnishes the deflection of the vertical in the meridian, and this can be used in the determination of the figure of the earth and in studies of isostasy.

There have been no changes during the three years covered by this report in the methods employed for field astronomical work, except an improvement of the radio apparatus which is used to receive and to record on a chronograph the radio time signals sent from the United States Naval Observatory. This improvement is described by E. J. Brown on page 19.

There were 83 azimuth determinations, 50 of which were for Laplace stations, 31 longitude determinations, and 12 latitude determinations in the United States during the three years covered by this report. These were nearly all made in the eastern part of the country in preparation for the readjustment of the triangulation net of this section. (See fig. 2.)

TIME SERVICE OF THE UNITED STATES NAVAL OBSERVATORY

The Naval Observatory furnishes a very useful time service which depends on star observations made each favorable night and on high-grade clocks to carry the time during the intermediate intervals. Time signals are sent out from the observatory each day at noon, at 10 p. m., and at 3 a. m. These time signals have been used by the Coast and Geodetic Survey in the determination of astronomical longitudes and also in its gravity work. The use of these time signals greatly reduces the cost of the longitude and gravity work. A brief account of the United States Naval Observatory time service by Paul Sollenberger, astronomer at the observatory, appears on page 20.

VARIATION OF LATITUDE

Observations for latitude were made at the observatory at Ukiah, Calif., each clear night during the three years covered by this report by H. G. Wrocklage, observer in charge. The observations have been made in accordance with the international plan and the results have been sent monthly to Prof. H. Kimura, chairman of the joint committee on the variation of latitude. The property involved at this station was given to the Coast and Geodetic Survey by the officials of the Reduced Geodetic Association among Neutral States (Association geodesique reduite entre Etats neutres) on the assurance of the officials of the Coast and Geodetic Survey that the station would be operated as a national institution. Data regarding the work at Ukiah are contained in the reports issued from time to time by Professor Kimura.

The Congress of the United States has authorized the resumption of observations at the variation of latitude station at Gaithersburg, Md., and has made an appropriation of funds for that purpose which will become available July 1, 1930. The observatory and the dwelling house at the Gaithersburg station are somewhat out of repair from disuse, and the first work at the station will consist in reconditioning these buildings. The observations will be made with the zenith telescope which had previously belonged to the Reduced Geodetic Association among Neutral States and which was used at the Gaithersburg station some years ago.

The United States Naval Observatory has been making observations continuously during the period covered by this report with the Ross zenith tube which was used for several years at the variation of latitude station at Gaithersburg, Md. This instrument was sold to the observatory by the officials of the Reduced Geodetic Association among Neutral States several years ago. A statement by Capt. Frank B. Littell regarding the variation of latitude work by the United States Naval Observatory is given on page 21.

ASTRONOMICAL WORK IN HAWAIIAN ISLANDS

In connection with hydrographic surveying in the vicinity of the Hawaiian Islands, observations for the determination of astronomical latitudes and longitudes were made at a number of isolated rocks and small islands which extend to the northwestward of the inhabited islands of the Hawaiian group. These observations were made by the usual methods, but somewhat larger probable errors were permitted than at astronomical stations in the continental United States.

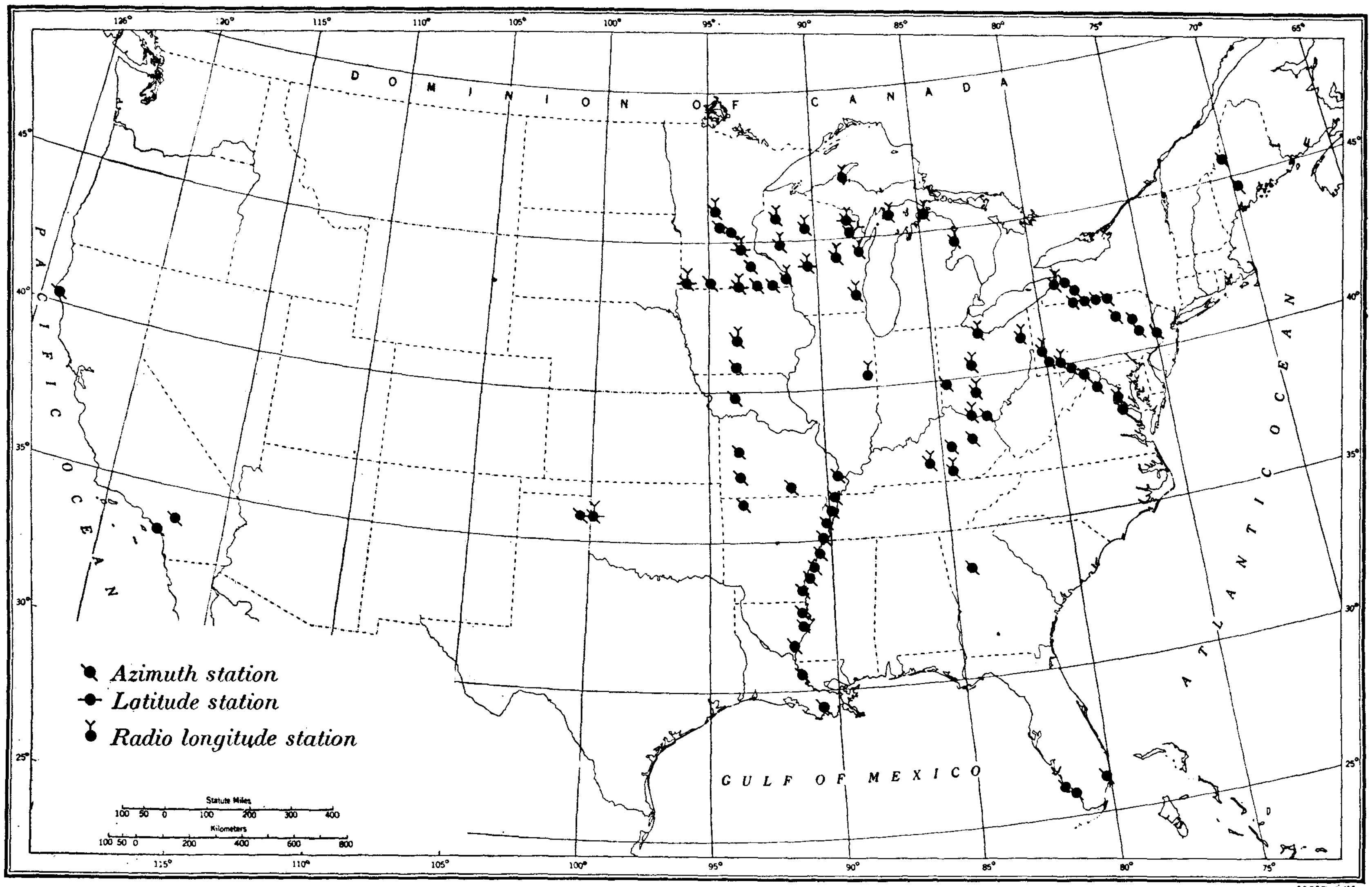


FIGURE 2.—Progress sketch, astronomical stations in the United States

MEASUREMENT OF BASE LINES

The methods employed by the Coast and Geodetic Survey in measuring first-order base lines are described in detail in Special Publication No. 120 of that organization, entitled "Manual of First-order Triangulation." The only change in methods since that publication was issued is in connection with the standardization of the tapes. Formerly when a number of base lines were measured by a party the tapes were standardized before and after the season's work. The instability of the invar and the resulting uncertainty of the changes in length during a long season led to the decision to have the base tapes restandardized after each two bases had been measured in the field. The procedure now is to measure two bases with a set of four 50-meter invar base tapes which have been standardized at the Bureau of Standards, and then return these tapes to Washington for restandardization and measure the next two bases with another set of newly standardized tapes, and so on.

It has been found that the invar tapes which are a year or more old do not change their lengths very much nor very rapidly, but there is always an uncertainty in the length of an invar tape, and it is therefore advisable that frequent standardizations be made. In this way the average lengths of the tapes as furnished by the two standardizations will be so near the truth that the resulting uncertainty in the lengths of the measured bases will be so small as to be negligible.

FIRST-ORDER BASE LINES

During the calendar years 1927, 1928, and 1929, 14 first-order bases were measured in the United States. Two of these bases were measured in connection with the survey of the city of Atlanta, Ga., and the others were for the control of the lengths in the first-order triangulation net of the United States. Three of these bases are west of the ninety-eighth meridian, and the remaining nine will be used in the readjustment of the triangulation east of the ninety-eighth meridian.

These bases were all measured as described in Special Publication No. 120 with 50-meter invar tapes. These tapes were standardized by comparison with the 5-meter iced bar by the United States Bureau of Standards, and not more than two or three bases were measured with the same tapes without being restandardized.

The location of the first-order bases, with their lengths and probable errors, is shown in the following table:

First-order bases measured in the United States

[January 1, 1927, to December 31, 1929]

Name of base and State	Length in meters	Probable error		Name of base and State	Length in meters	Probable error	
		Millimeters	Proportional part of 1 in—			Millimeters	Proportional part of 1 in—
Pahrump, Calif. and Nev.	24, 177. 1202	±6. 1	3, 960, 000	Hubbard, Iowa	9, 546. 7597	±6. 7	1, 420, 000
Decatur, Ga [1]	4, 632. 7312	±2. 2	2, 100, 000	Catesby, Okla	8, 931. 7010	±5. 9	1, 500, 000
Inman, Ga	2, 920. 9134	±1. 4	2, 100, 000	Burghill, Ohio	9, 010. 2085	±3. 4	2, 650, 000
Martinsburg, W. Va	9, 419. 4387	±3. 2	2, 900, 000	Portsmouth, Ohio	8, 597. 6781	±4. 1	2, 100, 000
Jackson, Minn	13, 626. 0157	±6. 9	1, 970, 000	Lucerne Valley, Calif	13, 968. 4989	±7. 8	1, 790, 000
Albert Lea, Minn	8, 016. 4303	±5. 6	1, 430, 000	Princeton, N. J	8, 544. 2348	±4. 0	2, 140, 000
Ridgeway, Minn [1]	9, 223. 2559	±5. 4	1, 740, 000	Knoxville, Pa	6, 091. 3481	±2. 6	2, 340, 000

[1] This is a broken base. The length given is the projected length of the base, but the probable error given is for the sum of the actual measured lengths.

FIRST-ORDER LEVELING

The Coast and Geodetic Survey is working on a plan which calls for lines of first-order leveling spaced at intervals of not over 100 miles over the area of the United States. The intermediate areas are to be traversed by lines of second and third-order levels.

All of the leveling done by the Coast and Geodetic Survey during the period covered by this report has been done with the Coast and Geodetic Survey type of instrument. The rod used consists of an invar strip fastened to a metal foot piece which is attached to a wooden staff. The instrument and rod have been described in various publications but in most detail in Coast and Geodetic Survey Special Publication No. 129, entitled "Geodetic Level and Rod."

GRADUATION OF RODS

Notable improvement has been made in the method of graduating the level rod by the use of an apparatus designed by D. L. Parkhurst, chief of the instrument division of the Coast and Geodetic Survey, and constructed under his immediate direction. With this apparatus a very high degree of perfection can be obtained in graduating the invar strip to centimeters and in placing the lowest graduation on the strip at a given distance from the foot of the rod.

CHANGE IN FIELD PROCEDURE

Since the rods are now graduated with such accuracy it has been possible to change the leveling procedure in the field with a resulting increase in rate of progress and decrease in unit cost. Formerly a rodman would remain at a turning point until both the forward and backward readings had been made on his rod, but now the two rodmen move forward at the same time as the observer on completion of the observations at a station. This method is described in an article entitled "Note on a Change, by the U. S. Coast and Geodetic Survey, in Precise Leveling Methods," which appeared in the Bulletin geodesique, No. 23, 1929, of the section of geodesy. This may seem to many engineers engaged in leveling operations to be an insignificant matter, yet it is of considerable importance because in the first-order leveling done by the Coast and Geodetic Survey the length of sight—that is, the distance from the instrument to either rod—may be as great as 150 meters on cloudy days or during any part of the day when the atmosphere is very steady. Of course the ground must be comparatively level in order to use such long lengths of sight.

Prior to the change in method of moving the rodmen the observer often found it uneconomical in time to use a length of sight more than about 110 meters. When the sights were longer than this he was delayed somewhat by the rodman who had to move from the rear of the observer at one station to the forward position at the next one. Of course with the new method the forward rodman must indicate in a clear and definite manner the exact spot that he used for his rod support in order that the rear rodman may easily find and identify the point.

LEVELING IN HAWAIIAN ISLANDS

During the period covered by this report first-order leveling was executed on the island of Oahu. This leveling consisted of a large circuit around the island and two crosslines which served to divide the large circuit into three smaller ones. In addition two small circuits were closed in the city of Honolulu and four short spurs were run back into the higher portions of the city.

The leveling on the island of Hawaii was done previous to the period covered by this report and consisted of a line extending from Hilo to the summit of Mauna Loa via Volcano House.

The results of all the first-order leveling in the Hawaiian Islands have been published in Special Publication No. 161 of the United States Coast and Geodetic Survey. This publication contains descriptions and elevations of the bench marks and sketches showing the location of the level lines.

ADJUSTMENT OF THE LEVEL NET OF THE UNITED STATES

A special adjustment of the first-order level net of the United States was made in 1926–27 for the purpose of studying the variation of mean sea level from a level surface. This adjustment, which comprised about 40,000 miles of leveling, showed rather conclusively that there was a slope upward of the mean sea-level surface with increase in latitude along the Atlantic and Pacific coasts and a slope downward from west to east along the coast of the Gulf of Mexico.

As a result of this special adjustment the officials of the United States Coast and Geodetic Survey decided to extend the study by making an adjustment of the combined level nets of the United States and Canada. In the combined adjustment the same methods were used as in the special adjustment. The combined nets were allowed to swing free on one sea-level connection, that at Galveston, Tex., and the adjustment gave the elevations with respect to Galveston of all other sea-level planes connected with the nets. These adjustments have been made solely for the purpose of study, and the results have not been used for fixing the elevations of bench marks.

A general adjustment of the combined level nets of the United States and Canada has been made also. In this adjustment all sea-level planes connected with the nets were held at zero elevation. This adjustment was made for the purpose of deriving the theoretically bets elevations of the thousands of bench marks distributed over the two countries.

At the time of writing this report the elevations of the junction-point bench marks only had been computed. It is expected that the officials of the Geodetic Survey of Canada and the United States Coast and Geodetic Survey will confer on the matter of deciding what shall be the accepted elevations for the bench marks, common to the two nets, which lie on or near the boundary between the two countries.

The results of the special adjustment of the combined level nets of the United States and Canada are discussed by Howard S. Rappleye on page 21.

LEVELING IN CALIFORNIA TO DETECT EARTH MOVEMENTS

The Coast and Geodetic Survey has during recent years executed 1,740 miles (2,800 km.) of first-order leveling in California in cooperation with the advisory committee in seismology of the Carnegie Institution of Washington. The purpose of this leveling is to furnish a basis for determining the vertical movement of ground during an earthquake or between earthquakes. Lines of first-order accuracy have been run along routes which are of interest from a seismological standpoint and substantial bench marks have been established at frequent intervals. If an earthquake should occur near one of these lines the leveling would be repeated in order to learn what vertical movement took place in the fault zone and how far from the zone the elevations were disturbed or changed. Of course there are occasions when an earth movement is suspected though no earthquake occurs. In such cases the levels could be rerun to disclose whether any changes in elevation had occurred since the first work was done.

STATISTICS FOR FIRST-ORDER LEVELING

There are given in the following table data concerning the various lines of first-order levels run by the Coast and Geodetic Survey during the period covered by this report. (See also fig. 3.)

Leveling by the United States Coast and Geodetic Survey

[January 1, 1927, to December 31, 1929]

Project	Chief of party	Length of line
		Kilometers
San Diego, Calif., to Yuma, Ariz. (part)	J. M. Smook	253
Springfield to Boston, Mass.	C. A. Schanck	178
La Jolla to San Diego, Calif.	G. E. Boothe	25
Yuma to Hassayampa, Ariz.	do	220
Yucca to Gila Bend, Ariz.	C. M. Thomas	329
Washington, D. C., to Richmond, Va.	J. P. Lushene	190
Calais to Bangor, Me.	Byron Williams	262
Gallup to Shiprock, N. Mex.	J. H. Brittain	156
Newcomb's store to Shiprock, N. Mex. (second order).	do	141
Vaughn to Logan, N. Mex.	do	204
Logan to Tucumcari, N. Mex. (second order).	do	82
Bangor to Danville, Me.	C. A. Schanck	172
Fort Kent to Bangor, Me.	do	326
St. Johnsbury to Fairlee, Vt.	Byron Williams	77
Springfield, Mass., to Whitehall, N. Y.	John Bowie, jr.	259
Loyalton, S. Dak., to Minot, N. Dak.	C. M. Thomas	465
Bellows Falls to Fairlee, Vt.	John Bowie, jr.	86
Oahu net, island of Oahu, Hawaii	L. G. Simmons	255
Grand Junction, Colo., to Salt Lake City, Utah.	J. H. Brittain	475
Atlanta, Ga.	Various	100
Goleta to Edna, Calif.	H. O. Fortin	187
San Diego to Oceanside, Calif. (via Ramona).	do	229
Santa Margarita to Bakersfield, Calif.	H. O. Fortin	185
Mojave to Barstow, Calif.	do	115
El Centro to Colton, Calif.	do	266
Honolulu, island of Oahu, Hawaii	L. G. Simmons	21
Lone Pine to the summit of Mount Whitney, Calif. (part).	J. H. Brittain	16
Montrose, Colo., to Farmington, N. Mex.	do	238
Farmington to Shiprock, N. Mex.	do	48
Tucumcari to Taylor Springs, N. Mex.	do	165
Greenup to Jackson, Ky.	H. O. Fortin	206
Somerset to Glasgow Junction, Ky.	do	164
Monett, Mo., to Memphis, Tenn.	P. C. Doran	582
Covington to Richmond, Va.	H. O. Fortin	414
Balcony Falls, Va., to Harpers Ferry, W. Va.	do	297
Taylor Springs, N. Mex., to Pueblo, Colo.	Charles Pierce	260
Philadelphia to Harrisburg, Pa.	J. D. Thurmond	188
Miscellaneous leveling in fragments too small to be listed separately.	Various	13
Total		7,849

TIDAL STATIONS AND OBSERVATIONS

Tidal observations are of importance to the geodesist because it is by this means that the plane of reference for the level net of the country is established. The observations are also of interest and value, in connection with first-order leveling, because they make possible a test of the stability of the coasts. A discussion of tidal observations by Paul Schureman is given on page 24.

GRAVITY DETERMINATIONS

Gravity observations were made by the Coast and Geodetic Survey during the period covered by this report at several stations in the West Indies and at a few stations in Hawaii. A brief discussion of this work by C. H. Swick will be found on page 26.

An invitation extended by the officials of the Carnegie Institution of Washington to Dr. F. A. Vening Meinesz, member of the Dutch Geodetic Commission, resulted in his coming to the United States with his gravity apparatus in the fall of 1928 for the purpose of making gravity-at-sea observations. A submarine was placed at his disposal by the Secretary of the United States Navy and observations were made in October and November, 1928, along the Atlantic coast of the United States and in the Caribbean Sea and the Gulf of Mexico. A description of this work by Miss Eleanor A. Lamson, of the United States Naval Observatory, will be found on page 29.

ISOSTATIC INVESTIGATIONS

Isostatic reductions have been computed not only for 25 stations in the West Indies, Hawaiian, and Philippine Islands but also for a number of gravity-at-sea stations, the observations at which had been made by Dr. Vening Meinesz on a Dutch submarine. About three years ago when the report to the Prague meeting was being prepared work was in progress on the isostatic reduction of the stations between Holland and Java determined by Doctor Meinesz in 1926 and early in 1927. The rest of these stations, about 100 in number, have since been completed and the results forwarded to Holland. The isostatic reductions of the gravity-at-sea stations determined from a United States submarine (see p. 31) were also made by the United States Coast and Geodetic Survey.

FIRST-ORDER LEVELING

U.S. Coast and Geodetic Survey

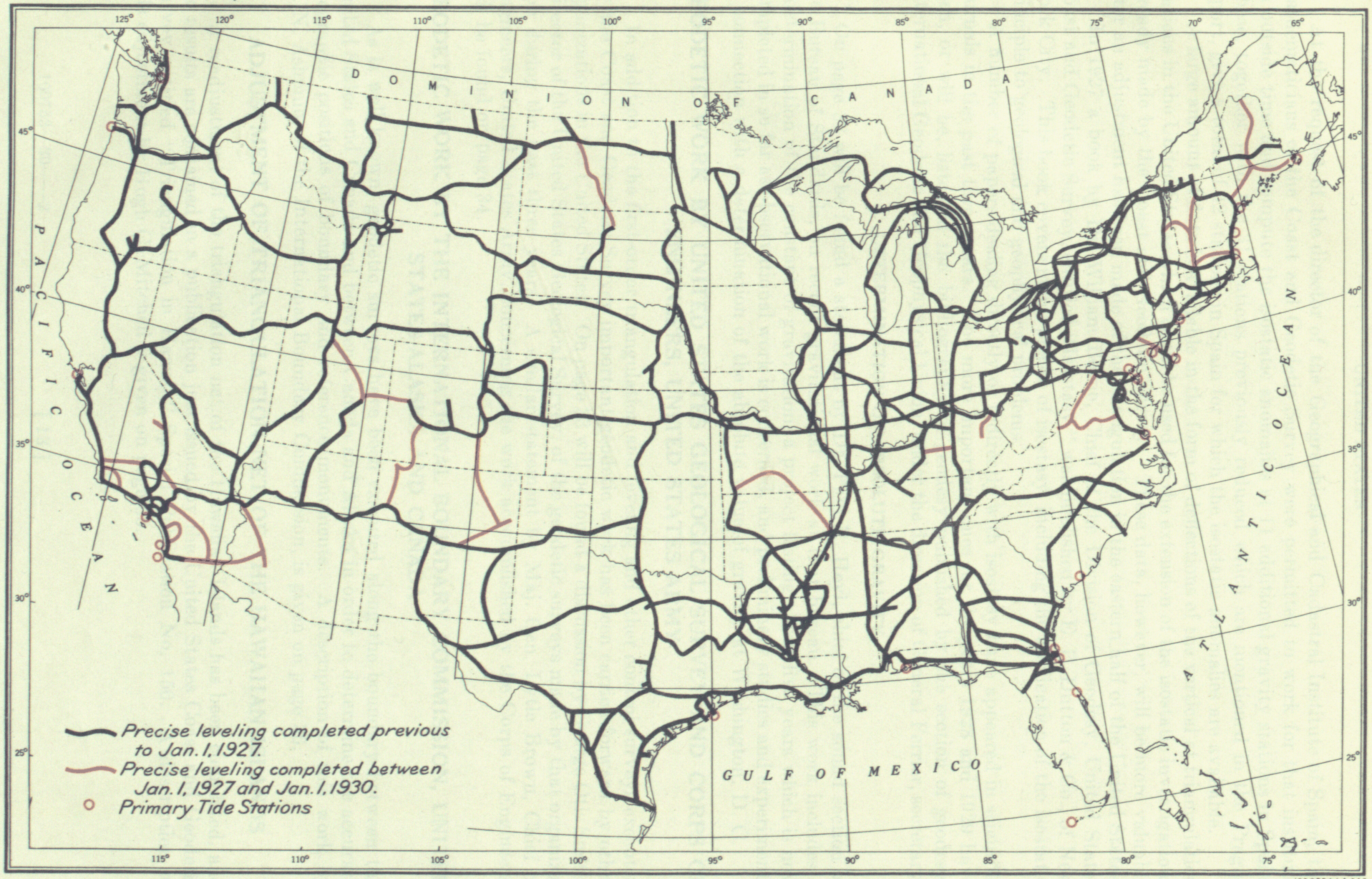


FIG. 3

At the request of the director of the Geographical and Cadastral Institute of Spain, the mathematicians of the Coast and Geodetic Survey were permitted to work for that institute on outside time and compute the isostatic anomalies at 11 additional gravity stations in Spain. These, together with the 31 stations previously reduced which are mentioned in the Prague report, give a total of 42 stations in Spain for which the isostatic anomalies are available.

A large amount of data is available in the form of deflections of the vertical at triangulation stations in the United States which could be used for the extension of the isostatic investigations already made by the Coast and Geodetic Survey. These data, however, will be more valuable after an adjustment has been made of the triangulation in the eastern half of the United States.

In 1927 a book by Dr. William Bowie, Chief of the Division of Geodesy, United States Coast and Geodetic Survey, entitled "Isostasy," was published by E. P. Dutton & Co., of New York City. This book covers many phases of isostasy, including the application of the isostatic principle to geological and geophysical problems.

A number of papers dealing directly or indirectly with isostasy have appeared in scientific journals in the past three years. The more important ones for the years 1928 and 1929 have been, or will be, listed in the bibliography of geodesy published by the section of geodesy, International Geodetic and Geophysical Union, under the direction of General Perrier, secretary.

DETERMINATION OF ABSOLUTE GRAVITY

On page 32 will be found a statement by Dr. Paul R. Heyl, chief of the sound section of the Bureau of Standards, on recent gravitational work at that bureau. This work includes a redetermination of the constant of gravitation, a project lasting about five years which is now completed in so far as observational work is concerned, and preliminary studies and experiments in connection with a determination of the absolute value of gravity at Washington, D. C.

GEODETIC WORK BY UNITED STATES GEOLOGICAL SURVEY AND CORPS OF ENGINEERS, UNITED STATES ARMY

In addition to the first-order triangulation and leveling and other control surveys executed by the Coast and Geodetic Survey important geodetic work has been carried forward by other organizations in the United States. On page 33 will be found a discussion by George Otis Smith, Director of the United States Geological Survey, of the geodetic surveys made by that organization during the past three years. A similar statement by Maj. Gen. Lytle Brown, Chief of Engineers, United States Army, concerning the work accomplished by the Corps of Engineers, will be found on page 34.

GEODETIC WORK BY THE INTERNATIONAL BOUNDARY COMMISSION, UNITED STATES-ALASKA AND CANADA

As is well known, geodetic surveys have been executed along the boundary between the United States and Canada and between Canada and Alaska in order to determine the accurate geographic positions of boundary and reference monuments. A description of this work by R. N. Ashmun, of the International Boundary Commission, is given on page 36.

ADJUSTMENT OF TRIANGULATION NET OF THE HAWAIIAN ISLANDS

A readjustment of the triangulation net of the Hawaiian Islands has been completed, and the results are contained in a publication just issued by the United States Coast and Geodetic Survey entitled "Triangulation in Hawaii," Special Publication No. 156. A description of this adjustment by Hugh C. Mitchell is given on page 36.

PROJECTIONS FOR MAPS

For a number of years the Coast and Geodetic Survey has been quite active in designing projections for maps and in discussing the theory and uses of projections for various purposes. A discussion by O. S. Adams of recent work along this line in the United States is given on page 37.

SECTION OF GEODESY, AMERICAN GEOPHYSICAL UNION

Very shortly after the organization of the International Research Council and some of its unions at Brussels in 1919 the American Geophysical Union was organized in the United States as a committee of the National Research Council, with headquarters at Washington, D. C. It is composed of sections which correspond to the sections of the International Geodetic and Geophysical Union as originally organized. The American Geophysical Union has not yet organized a section of scientific hydrology to correspond with a similar section of the International Geodetic and Geophysical Union, which was added at the time of the Rome meeting of the international union.

The American Geophysical Union holds annual meetings during the latter part of April or early in May. Meetings of the several sections are also held at the same time, at which reports on the work accomplished during the year are made, international aspects of the several subjects covered by the sections are discussed, committee reports are made, and provision is made for the administration of the several sections during the following year. The proceedings of the meetings of the American Geophysical Union and its sections appear as bulletins of the National Research Council. Occasionally the papers or reports made to the section meetings appear in full in scientific journals of the United States and are abstracted in the proceedings of the union.

On January 1, 1930, the officials of the union were: President, William Bowie, Chief, Division of Geodesy, United States Coast and Geodetic Survey; vice president, L. H. Adams, physical chemist, geophysical laboratory, Carnegie Institution of Washington; general secretary, John A. Fleming, acting director, department of terrestrial magnetism, Carnegie Institution of Washington. The officials of the Section of Geodesy are: President, W. D. Lambert, senior mathematician, United States Coast and Geodetic Survey; vice president, L. J. Briggs, assistant director, United States Bureau of Standards; secretary, H. G. Avers, senior mathematician, United States Coast and Geodetic Survey.

BOARD OF SURVEYS AND MAPS

The board of surveys and maps is composed of representatives of the various Federal map-making organizations. Its purpose is to study and assist in coordinating the mapping and surveying activities of the different organizations engaged in this class of work.

The board maintains a map information office in the Interior Department, Washington, D. C., in charge of J. H. Wheat. This office keeps in close touch with organizations making and publishing maps and maintains quite a large file of maps for consultation purposes. Inquiries addressed to the map information office, in case they can not be answered directly, are forwarded to the proper agency for attention.

GEODETIC PUBLICATIONS ISSUED SINCE JANUARY 1, 1927

UNITED STATES COAST AND GEODETIC SURVEY

Descriptions of bench marks in the United States. (Reprinted from Appendix 3, Report for 1903, by John F. Hayford.) Special Publication No. 131. 1927.

Geodetic operations in the United States, January 1, 1924, to December 31, 1926. William Bowie. Special Publication No. 134. 1927.

Manual of first-order traverse. Caspar M. Durgin and Walter D. Sutcliffe. Special Publication No. 137. 1927.

Manual of triangulation computation and adjustment. Walter F. Reynolds. Special Publication No. 138. 1928.

Elements of map projection with applications to map and chart construction. (Revised edition.) Charles H. Deetz and Oscar S. Adams. Special Publication No. 68. 1928.

Comparison of old and new triangulation in California. William Bowie. Special Publication No. 151. 1928.

Manual of first-order leveling. Henry G. Avers. Special Publication No. 140. 1929.

Manual of second and third order triangulation and traverse. C. V. Hodgson. Special Publication No. 145. 1929.

Conformal projection of the sphere within a square. Oscar S. Adams. Special Publication No. 153. 1929.

Precise leveling in Texas. (Revised edition.) Henry G. Avers. Special Publication No. 77. 1929.

Geodetic surveys—methods, instruments, and purposes. (Revised edition.) Serial No. 257. 1929.

Formulas and tables for the computation of geodetic positions. (Seventh edition.) Special Publication No. 8. 1929.

Bilby steel tower for triangulation. Jasper S. Bilby. Special Publication No. 158. 1929.

The Bowie method of triangulation adjustment as applied to the first-order net in the western part of the United States. Oscar S. Adams. Special Publication No. 159. 1930.

First-order leveling in Hawaii. Howard S. Rappleye. Special Publication No. 161. 1929.

The United States Coast and Geodetic Survey, its work, methods, and organization. (1929 revised edition.) Special Publication No. 23. 1929.

UNITED STATES GEOLOGICAL SURVEY

Topographic instructions of the United States Geological Survey. C. H. Birdseye. United States Geological Survey Bulletin 788. 1928. (Includes a section on administration by H. M. Frye, sections on triangulation, transit traverse, and leveling by E. M. Douglas, a section on topographic mapping by W. M. Beaman, and a section on map compilation from aerial photographs by T. P. Pendleton.)

Formulas and tables for the construction of polyconic projections. C. H. Birdseye. United States Geological Survey Bulletin 809. 1929.

UNITED STATES WAR DEPARTMENT

Topography and surveying, geodetic surveying. Prepared under direction of the Chief of Engineers. Training Manual No. 2180-60. 1928.

Topography and surveying, instrumental methods. Prepared under direction of the Chief of Engineers. Training Manual No. 2180-30. 1929.

Topography and surveying, meridian determination. Prepared under direction of the Chief of Engineers. Training Manual No. 2180-45. 1928.

TRIANGULATION OF NORTH AMERICA

In Figure 4 is shown the triangulation of the United States, Canada, and Mexico, already completed or to be completed in the immediate future. The data for the Mexican triangulation were furnished by Dr. Pedro C. Sánchez, El Director de Estudios Geográficos y Climatológicos, and those for the Canadian by Noel J. Ogilvie, Director, Geodetic Survey of Canada.

It will be noticed that the triangulations of Canada and the United States join at a number of places. In fact, the networks of the two countries form a single unit. It may also be seen that an arc of first-order triangulation has been extended along the western coast of Canada and through southeast Alaska to a point in longitude 135° 23′ and latitude 59° 27′.

The triangulations of the United States and Mexico are connected at the boundary in the vicinity of the ninety-eighth meridian and also between California and Lower California. It is expected that other connections between the nets of Mexico and the United States will be made in the very near future.

Practically all the triangulation shown on Figure 4 is of the first order. It is all computed on the Clarke spheroid of 1866 as expressed in meters and is based on the initial station, Meades Ranch, in central Kansas, the latitude of which is 39° 13′ 26″.686 and the longitude 98° 32′ 30″.506.

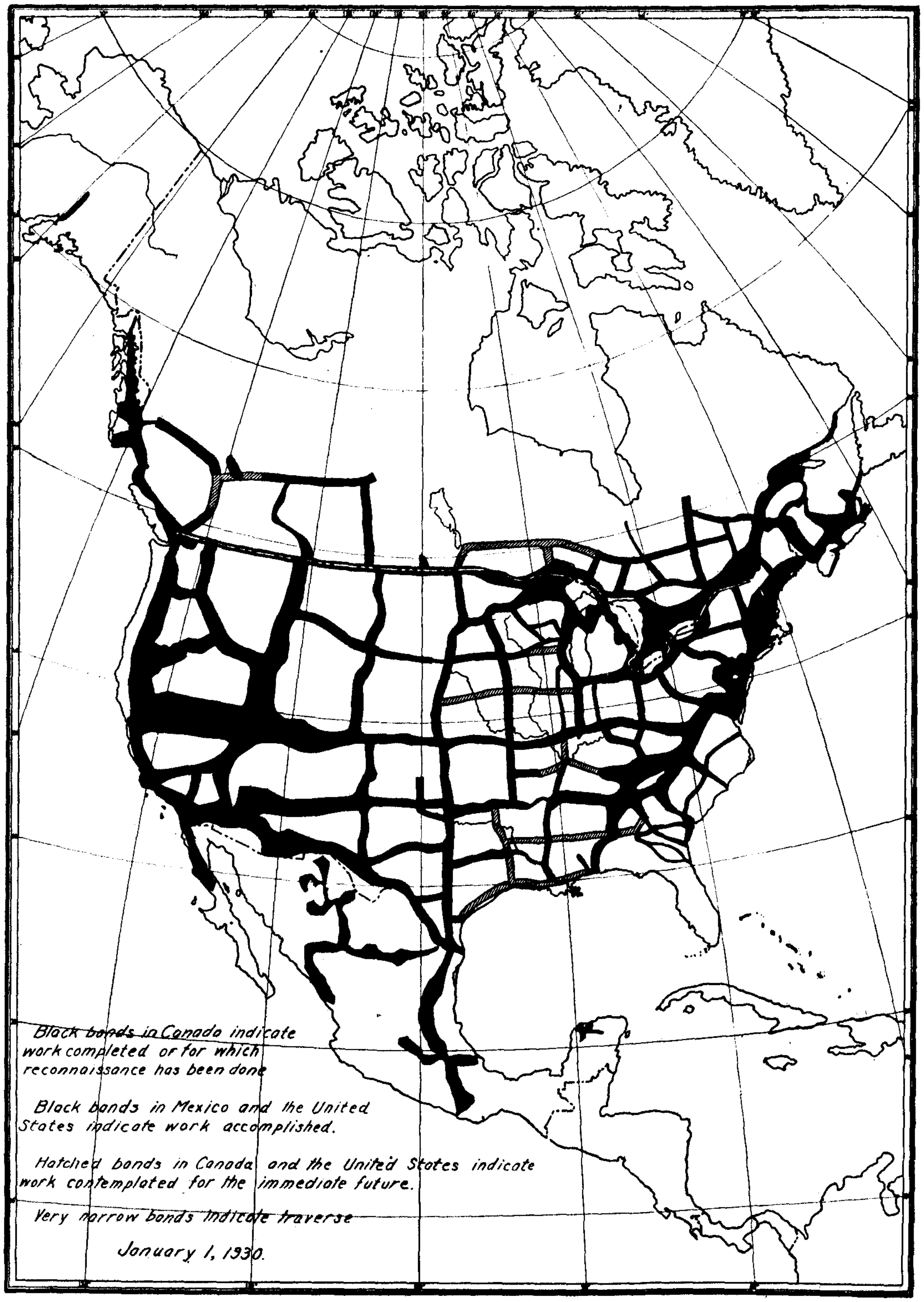


FIGURE 4.—Triangulation of North America

In the readjustment of the triangulation net of the United States the longitude and latitude of Meades Ranch were held to the values used when the United States standard datum was adopted about 30 years ago. For scientific purposes it would have been preferable to use the Hayford or International Ellipsoid of Reference in the readjustment but this was impracticable because of the tremendous number of charts and maps which have been based on the Clarke spheroid and because of the wide use by engineers, surveyors, and geographers of the Clarke spheroid in their operations.

It is hoped that the triangulation of North America will be extended southward in the near future to cover Central America and even into South America.

HAYFORD OR INTERNATIONAL SPHEROID

It has not been practicable to place the triangulation of the United States on the Hayford or International Spheroid of Reference which was adopted by the section of geodesy, International Geodetic and Geophysical Union, at its meeting in Madrid, Spain, in 1924. However, it is believed to be practicable to compute the junction points of the triangulation net, and also stations at which astronomical observations have been made, on the Hayford spheroid by means of some method which should not require a great amount of time and work.

A study is now being made by the Coast and Geodetic Survey to find out if it is possible to devise a method that can be used in transferring the triangulation net of this country from the Clarke to the Hayford spheroid. If such a method can be discovered efforts will be made to compute on the Hayford spheroid the stations at the junction points of the net and those stations at which astronomical observations have been made. If this can be done then the triangulation net of the United States and, in fact, of North America will be more useful for determinations of the figure of the earth and in isostatic studies, such as those to determine the approximate location and extent of masses of material near the earth's surface in the vicinity of the deflection stations, which have abnormally great or small densities.

TECHNICAL MANUALS

For a number of years the Coast and Geodetic Survey has found it desirable to issue manuals for its several classes of work. A manual gives the specifications for the work, the accuracy desired, the limits of error allowable, and detailed directions and information which will enable the engineer in the field and the mathematician in the office to carry on the work successfully.

There are given below the titles of the several manuals that have been recently issued by the United States Coast and Geodetic Survey on the different classes of geodetic work.

Special Publication 120, Manual of First-Order Triangulation.
Special Publication 137, Manual of First-Order Traverse.
Special Publication 138, Manual of Triangulation Computation and Adjustment.
Special Publication 140, Manual of First-Order Leveling.
Special Publication 145, Manual of Second and Third Order Triangulation and Traverse.

SPECIAL ARTICLES

ADJUSTMENT OF THE TRIANGULATION IN SOUTHEAST ALASKA ON THE NORTH AMERICAN DATUM OF 1927

By WALTER F. REYNOLDS, *Senior Mathematician, United States Coast and Geodetic Survey*

One of the most noteworthy accomplishments of the United States Coast and Geodetic Survey during the period from January 1, 1927, to December 31, 1929, was the adjustment of the triangulation of southeast Alaska on the North American datum of 1927.

For many years after the purchase of Alaska by the United States from Russia triangulation was executed there at various detached points. Toward the close of 1901 nine different groups of triangulation schemes in southeast Alaska had been joined to make one continuous scheme and a datum known as the southeast Alaska datum was adopted.

In 1915 practically all the triangulation in Alaska was based on three separate datums, namely, southeast Alaska, Valdez, and Yukon. Up to this time no Laplace azimuths had been observed and very few bases had been measured, so that a great part of the triangulation was weak.

Shortly after 1915 the United States Coast and Geodetic Survey made a cooperative agreement with the Geodetic Survey of Canada to carry a scheme of first-order triangulation from Point Roberts in the vicinity of the Straits of Fuca in the northwest part of the State of Washington, along the west coast of British Columbia to Dixon Entrance, and then through Clarence Strait, Frederick Sound, and Stephens Passage to Skagway. The field observations on this scheme were completed in 1925.

The adjustment of the triangulation along the west coast of British Columbia from Point Roberts, Wash., to Dixon Entrance, Alaska, was made by the Geodetic Survey of Canada. As a result of this adjustment the United States Coast and Geodetic Survey was furnished starting data in Dixon Entrance on the North American datum of 1927, the triangulation in the United States west of the ninety-eighth meridian having previously been computed on that datum.

The first-order arc of triangulation from Dixon Entrance to Skagway was adjusted in the Division of Geodesy of the United States Coast and Geodetic Survey. Instead of a single adjustment for the entire arc, the work was divided into 14 sections which were adjusted separately. This method was due to two causes: First, the field observations were not completed at the time the adjustment was begun; second, to adjust the entire scheme in a single solution would have required a great many equations and would have made their solution unusually heavy.

The lengths of the lines in the southeast Alaska arc are fixed by 10 measured bases and by the length of the line Chacon-Dundas furnished by the Geodetic Survey of Canada. Seven Laplace azimuths and the azimuth of the line Chacon-Dundas served to fix the arc in azimuth. In order that the adjustment could be made in sections and still be controlled by the Laplace azimuths, the discrepancy developed between each two consecutive azimuths was first found and then prorated to the sections according to the number of angles necessary to turn through in each. The arc was fixed in position by the position of the line Chacon-Dundas furnished by the Geodetic Survey of Canada.

During the year 1928 the positions of all the first-order triangulation stations along this arc in southeast Alaska were computed on the North American datum of 1927. The manuscript copy of the results has been sent to the printer and will probably be published during the summer of 1930. This publication, entitled "Triangulation in Southeast Alaska," will appear as Special Publication No. 164 of the United States Coast and Geodetic Survey. It will contain not only the geographic positions and descriptions of the triangulation stations but also a discussion of the errors and methods of adjustment.

At the close of the year 1929 the positions of all the stations of the second-order triangulation through Chatham Strait, which is connected to the first-order triangulation in Frederick Sound and Lynn Canal, and the greater part of the third-order triangulation in southeast Alaska, which has been executed since 1912, had been adjusted on the North American datum of 1927.

After this computation has been completed it will be necessary to compute the triangulation, the field work of which was done previous to 1912. However, this older triangulation will not require the rigid adjustment given the new work, but can be fitted into the new by simpler methods.

With the adjustment of the triangulation of southeast Alaska nearly completed, it is now possible to make the charts there consistent not only in themselves but with those on the coasts of the United States.

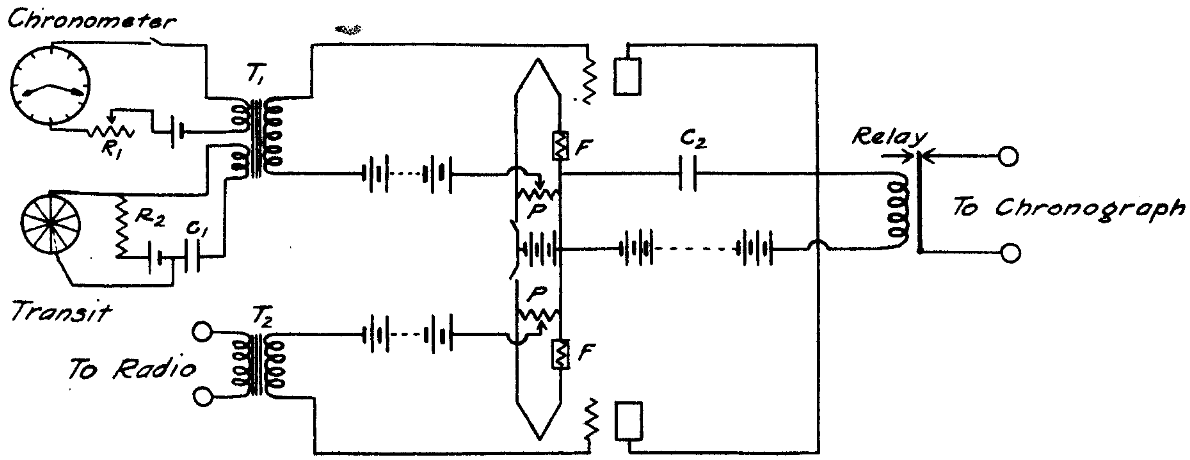
NEW EQUIPMENT FOR LONGITUDE DETERMINATIONS

By E. J. Brown, *Hydrographic and Geodetic Engineer, United States Coast and Geodetic Survey*

At the beginning of the field season of 1928 the long-wave radio time signal recorders were replaced by short-wave apparatus, and since that time the short-wave time signals from Arlington have been used to control all determinations of astronomical longitude. The short-wave recorders have proven more dependable than the long-wave apparatus, and their use has resulted in a marked increase in the operating efficiency of the astronomical field parties.

The short-wave recording apparatus consists of a sensitive short-wave receiver coupled to an additional power amplifier designed for signal rectification. During the past year an amplifier has been developed which in addition to amplifying and rectifying the signals serves to eliminate the effect of time lag of the various circuits.

A schematic diagram of the longitude circuit arrangement is given in Figure 5 showing the principles of the amplifier in detail. It will be noted that the impulses from the radio receiver,



C_1=1.0 mfd.
C_2=0.1 mfd.
F =Filament ballast.
R_1=0 to 2,000 ohms.
R_2=20,000 ohms.
T_1=Double button microphone transformer.
T_2=Standard audio-frequency transformer.

FIGURE 5.—Radio-signal amplifier

the impersonal transit micrometer, and the break-circuit chronometer are all passed through the amplifier and caused to actuate a single relay. The chronometer circuit is common to the other two circuits and any lag originating in this circuit will not affect the longitude results, provided such lag remains constant. Lags occurring in the transit and radio circuits are of opposite sign and their effect is eliminated if they are of the same magnitude. By providing nearly identical electrical paths for the three impulses the amplifier insures an effective constancy of lag in the chronometer circuit and reduces the residual lag of the radio and transit circuits to a negligible amount.

The transit micrometer is of the make-circuit type, as indicated in the diagram. To avoid the double record resulting from making and breaking the circuit at each contact the transit circuit shown is used. The condenser C_1 charges slowly through the resistance R_2 while the circuit is open at the micrometer. When contact is made at the micrometer the condenser is short circuited and discharges through the primary of the microphone transformer. The system is very positive in its action and gives sharp chronograph breaks which are of the same time duration regardless of the declination of the star being observed.

The amplification given the impulse from the chronometer permits the use of a very low current, about 1.5 milliamperes, through the break circuit device. The use of such a low current prevents any possibility of burning or sticking of the contact points and often results in better chronometer rates.

THE UNITED STATES NAVAL OBSERVATORY TIME SERVICE

By Paul Sollenberger, *Astronomer, United States Naval Observatory*

The most noteworthy changes in the United States Naval Observatory time service during the past three years have been the addition of a new regular time signal at 8 hours Greenwich civil time (3 a. m., eastern standard time), and the addition of 2 new radio frequencies, 8,030 and 12,045 kilocycles for the transmission of the signals at 3 hours and 17 hours. The 8-hour signal serves many useful purposes. It is received in darkness throughout the United States, Canada, and much of the Pacific thus rendering possible the making of stellar observations practically simultaneously with the reception of the signal anywhere in that area. A further advantage of the hour selected is that it gives two signals spaced by an interval of only 5 hours. The interval of 10 hours, which was the best available formerly, was too long for the rating of gravity pendulums, or for other work involving the determination of short interval rates.

The signals at 3 and 17 hours are now sent via the Arlington and Annapolis radio stations on six different frequencies. Since the present facilities at the observatory do not make it possible to record simultaneously so many frequencies, it has been the custom not to measure the 690-kilocycle signal, which is in the radiophone broadcast band, and to measure only one of the high-frequency signals. The 690-kilocycle signal is received only in the vicinity of Washington and is relatively unimportant. The high-frequency signals are widely used, however, and it is desirable that the transmission times of all of them be known. Fortunately their lags are all small, and for most purposes they may all be assumed to go out at the same time. It is hoped that arrangements may soon be made for measuring them all.

Another improvement in the service given to the public has been effected by distributing the corrections to the time signals weekly instead of monthly. Owing to various causes, it has not been possible to send out the data as soon as the week is finished, but the average time elapsing between the sending of a signal and mailing of the corrections has been much reduced. The reception times of foreign time signals received at the Naval Observatory have been added to the correction sheets. The rythmic signals sent by FYL at Bordeaux, France, at 8 hours, and by GBR at Rugby, England, at 18 hours, are usually observed.

Practically since Arlington began to transmit Naval Observatory time signals it had been operated by a direct line from the Naval Observatory. Annapolis was operated by the American Telephone & Telegraph Co. by means of relay equipment located in their Washington exchange. This equipment was not under the control of the observatory, and introduced lag which was larger than necessary. It was decided that the most logical means of control for all stations would be by means of a direct line from the observatory to the central radio-control room of the Navy Department. Accordingly, such a line was installed. Special precautions were taken to reduce lag in the operation of the line. At the observatory end there were no relays, except one operated by the transmitting clock, it being undesirable to put the heavy line current directly into the clocks. At radio central a series of relays were put on the line, one for each station to be operated.

In December, 1928, a board met at the Navy Department for the purpose of considering time signals and their distribution. The board considered and made recommendations on a number of subjects. One of these recommendations was that the time signal code be changed so as to make each minute distinctive. In this manner persons desiring to know the time with approximate accuracy would not be compelled to listen till the end of the signal in order to determine the minute. In order to determine whether it met with general approval, the proposed change was referred to several interested services and organizations, including the merchant marine interests of the country, which were markedly favorable to the change. Modifications are now being effected at naval radio stations to permit of the emission of the selective time signal, and it is expected that the revised code will be inaugurated at an early date.

Another recommendation of the board was that the line from the observatory to the Navy Department, previously used as a metallic pair, be split and made into two independent lines with ground returns. By this means greater freedom from breakdown could be secured. This recommendation has been placed in effect.

While there have been various improvements in the service, as partly described above, there is still much room for advancement. The ideal system would be one which would make time signals continuously available, and which would furnish their corrections, if corrections were necessary, without delay. The obstacle in the way of continuous time signals, or even more frequent time signals, is the fact that the use of the radio stations or transmitters can not be secured for the purpose. The administration of the Naval Observatory is keenly aware that the advances of science in many lines make necessary a policy of continuous research and improvement in time distribution.

Experimental work at the observatory has accomplished the successful determination of time with a new type of instrument, a photographic telescope of fixed position, and investigations are also being conducted on the subject of timekeepers. It is planned to purchase a new Shortt clock. Developments in crystal oscillators are being carefully watched, and it is hoped that crystal control may be adapted to the control of the speed of a new type chronograph which is now being developed at the observatory. While such work is necessarily slow, it is hoped that something may be accomplished which will add substantially to the accuracy of the methods of time determination and distribution.

VARIATION OF LATITUDE OBSERVATIONS

By CAPTAIN FRANK B. LITTELL (*Math.*), *United States Navy, United States Naval Observatory*

During the period from January 1, 1927, to December 31, 1929, the observations for variation of latitude at the United States Naval Observatory, Washington, D. C., which were begun in 1915, have been continued with the Ross reflex photographic zenith tube.

Eight groups of eight stars each are used and two consecutive groups are under observation at any given time, thus conforming to the polygon system of observation by which the errors of the star places are eliminated from the resulting variation of latitude.

The results for the year 1927 were published in the Astronomical Journal of January 14, 1929, and those for the year 1928 were published in the same journal on March 5, 1930. Those for 1929 are in preparation for publication.

FURTHER STUDY OF THE VARIATION OF MEAN SEA LEVEL FROM A LEVEL SURFACE

By HOWARD S. RAPPLEYE, *Associate Mathematician, United States Coast and Geodetic Survey*

In United States Coast and Geodetic Survey Special Publication No. 134, Geodetic Operations in the United States, January 1, 1924, to December 31, 1926, a special article by Henry G. Avers, chief mathematician, division of geodesy of this bureau, contains an account of a special adjustment of the first-order level net of the United States which was made for the express purpose of testing the variation of the plane of mean sea level from a level surface. Since that adjustment, which is known in this bureau as the 1927 special adjustment, another and more extensive adjustment has been made which includes the first-order level nets of both the United States and Canada.

The 1929 special adjustment, as this last study is called, involves 103,000 kilometers of first-order leveling. The number of closed circuits in the combined nets of both countries was 244. The adjustment was made by the method of condition equations, each circuit giving rise to an equation. All the closed circuits of leveling were made consistent without holding any sea-level connections.

After the closure errors had been eliminated by the least-squares adjustment the observed difference of elevation from mean sea level at Galveston, Tex., to the junction bench mark at Houston, Tex., was used to determine an elevation for the junction bench at Houston. The elevations of all the other junction points in the combined net were then computed on the basis of this single junction elevation at Houston, Tex., using the differences resulting from the adjustment.

After all the junction elevations had been computed observed differences were used to carry the elevation from the nearest junction bench mark to the plane of mean sea level at each of the various tide stations. Thus was derived at each tide station the elevation of the plane of mean sea level in relation to the plane of mean sea level at Galveston, Tex., as determined by first-order leveling which had been made consistent within itself by adjustment.

The results of this study are set forth in the accompanying table. It will be noticed from even a casual inspection of the table that the results of the 1927 special adjustment are confirmed and that the upward slope continues northward along the Atlantic and Pacific coasts of the Dominion of Canada. A plus sign in the table indicates that mean sea level at the port is higher than mean sea level at the reference port.

It will be noted that there is a distinct tendency for the plane of mean sea level to slope downward in an easterly direction along the Gulf coast of the United States and upward in a northerly direction along both the Atlantic and Pacific coasts of the continent of North America, and, as might be expected from the slope along the Gulf coast, that the general elevation of the plane of mean sea level on the Pacific coast is higher than that on the Atlantic coast.

This same result is found in the accurate leveling carried across the Isthmus of Panama, which shows the plane of mean sea level on the Pacific side of the isthmus to be 206 millimeters higher than it is at the Atlantic end of the Panama Canal.

Relative elevations of mean sea level determined by the 1929 special adjustment

Station	Based on: Galveston	Biloxi	Pensacola	Cedar Keys	St. Augustine	Fernandina	Brunswick	Norfolk	Old Point Comfort	Cape May	Atlantic City	Annapolis	Baltimore	Perth Amboy	Fort Hamilton	Boston	Portland	Yarmouth	Halifax	Father Point	San Diego	San Pedro	San Francisco	Fort Stevens	Anacortes	Seattle	Vancouver	Prince Rupert
GULF COAST	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*
Galveston	0.00	+0.09	+0.05	+0.08	+0.27	+0.20	+0.16	+0.14	+0.28	−0.02	−0.03	+0.17	+0.18	−0.01	−0.03	−0.07	−0.12	−0.05	−0.08	−0.20	−0.33	−0.31	−0.34	−0.59	−0.45	−0.48	−0.50	−0.58
Biloxi	−0.09	0.00	−0.04	−0.01	+0.18	+0.11	+0.07	+0.05	+0.19	−0.11	−0.12	+0.08	+0.09	−0.10	−0.12	−0.16	−0.21	−0.14	−0.17	−0.29	−0.42	−0.40	−0.43	−0.68	−0.54	−0.57	−0.59	−0.67
Pensacola	−0.05	+0.04	0.00	+0.03	+0.22	+0.15	+0.11	+0.09	+0.23	−0.07	−0.08	+0.12	+0.13	−0.06	−0.08	−0.12	−0.17	−0.10	−0.13	−0.25	−0.38	−0.36	−0.39	−0.64	−0.50	−0.53	−0.55	−0.63
Cedar Keys	−0.08	+0.01	−0.03	0.00	+0.19	+0.12	+0.08	+0.06	+0.20	−0.10	−0.11	+0.09	+0.10	−0.09	−0.11	−0.15	−0.20	−0.13	−0.16	−0.28	−0.41	−0.39	−0.42	−0.67	−0.53	−0.56	−0.58	−0.66
ATLANTIC COAST																												
St. Augustine	−0.27	−0.18	−0.22	−0.19	0.00	−0.07	−0.11	−0.13	+0.01	−0.29	−0.30	−0.10	−0.09	−0.28	−0.30	−0.34	−0.39	−0.32	−0.35	−0.47	−0.60	−0.58	−0.61	−0.86	−0.72	−0.75	−0.77	−0.85
Fernandina	−0.20	−0.11	−0.15	−0.12	+0.07	0.00	−0.04	−0.06	+0.08	−0.22	−0.23	−0.03	−0.02	−0.21	−0.23	−0.27	−0.32	−0.25	−0.28	−0.40	−0.53	−0.51	−0.54	−0.79	−0.65	−0.68	−0.70	−0.78
Brunswick	−0.16	−0.07	−0.11	−0.08	+0.11	+0.04	0.00	−0.02	+0.12	−0.18	−0.19	+0.01	+0.02	−0.17	−0.19	−0.23	−0.28	−0.21	−0.24	−0.36	−0.49	−0.47	−0.50	−0.75	−0.61	−0.64	−0.66	−0.74
Norfolk	−0.14	−0.05	−0.09	−0.06	+0.13	+0.06	+0.02	0.00	+0.14	−0.16	−0.17	+0.03	+0.04	−0.15	−0.17	−0.21	−0.26	−0.19	−0.22	−0.34	−0.47	−0.45	−0.48	−0.73	−0.59	−0.62	−0.64	−0.72
Old Point Comfort	−0.28	−0.19	−0.23	−0.20	−0.01	−0.08	−0.12	−0.14	0.00	−0.30	−0.31	−0.11	−0.10	−0.29	−0.31	−0.35	−0.40	−0.33	−0.36	−0.48	−0.61	−0.59	−0.62	−0.87	−0.73	−0.76	−0.78	−0.86
Cape May	+0.02	+0.11	+0.07	+0.10	+0.29	+0.22	+0.18	+0.16	+0.30	0.00	−0.01	+0.19	+0.20	+0.01	−0.01	−0.05	−0.10	−0.03	−0.06	−0.18	−0.31	−0.29	−0.32	−0.57	−0.43	−0.46	−0.48	−0.56
Atlantic City	+0.03	+0.12	+0.08	+0.11	+0.30	+0.23	+0.19	+0.17	+0.31	+0.01	0.00	+0.20	+0.21	+0.02	0.00	−0.04	−0.09	−0.02	−0.05	−0.17	−0.30	−0.28	−0.31	−0.56	−0.42	−0.45	−0.47	−0.55
Annapolis	−0.17	−0.08	−0.12	−0.09	+0.10	+0.03	−0.01	−0.03	+0.11	−0.19	−0.20	0.00	+0.01	−0.18	−0.20	−0.24	−0.29	−0.22	−0.25	−0.37	−0.50	−0.48	−0.51	−0.76	−0.62	−0.65	−0.67	−0.75
Baltimore	−0.18	−0.09	−0.13	−0.10	+0.09	+0.02	−0.02	−0.04	+0.10	−0.20	−0.21	−0.01	0.00	−0.19	−0.21	−0.25	−0.30	−0.23	−0.26	−0.38	−0.51	−0.49	−0.52	−0.77	−0.63	−0.66	−0.68	−0.76
Perth Amboy	+0.01	+0.10	+0.06	+0.09	+0.28	+0.21	+0.17	+0.15	+0.29	−0.01	−0.02	+0.18	+0.19	0.00	−0.02	−0.06	−0.11	−0.04	−0.07	−0.19	−0.32	−0.30	−0.33	−0.58	−0.44	−0.47	−0.49	−0.57
Fort Hamilton	+0.03	+0.12	+0.08	+0.11	+0.30	+0.23	+0.19	+0.17	+0.31	+0.01	0.00	+0.20	+0.21	+0.02	0.00	−0.04	−0.09	−0.02	−0.05	−0.17	−0.30	−0.28	−0.31	−0.56	−0.42	−0.45	−0.47	−0.55
Boston	+0.07	+0.16	+0.12	+0.15	+0.34	+0.27	+0.23	+0.21	+0.35	+0.05	+0.04	+0.24	+0.25	+0.06	+0.04	0.00	−0.05	+0.02	−0.01	−0.13	−0.26	−0.24	−0.27	−0.52	−0.38	−0.41	−0.43	−0.51
Portland	+0.12	+0.21	+0.17	+0.20	+0.39	+0.32	+0.28	+0.26	+0.40	+0.10	+0.09	+0.29	+0.30	+0.11	+0.09	+0.05	0.00	+0.07	+0.04	−0.08	−0.21	−0.19	−0.22	−0.47	−0.33	−0.36	−0.38	−0.46
Yarmouth	+0.05	+0.14	+0.10	+0.13	+0.32	+0.25	+0.21	+0.19	+0.33	+0.03	+0.02	+0.22	+0.23	+0.04	+0.02	−0.02	−0.07	0.00	−0.03	−0.15	−0.28	−0.26	−0.29	−0.54	−0.40	−0.43	−0.45	−0.53
Halifax	+0.08	+0.17	+0.13	+0.16	+0.35	+0.28	+0.24	+0.22	+0.36	+0.06	+0.05	+0.25	+0.26	+0.07	+0.05	+0.01	−0.04	+0.03	0.00	−0.12	−0.25	−0.23	−0.26	−0.51	−0.37	−0.40	−0.42	−0.50
Father Point	+0.20	+0.29	+0.25	+0.28	+0.47	+0.40	+0.36	+0.34	+0.48	+0.18	+0.17	+0.37	+0.38	+0.19	+0.17	+0.13	+0.08	+0.15	+0.12	0.00	−0.13	−0.11	−0.14	−0.39	−0.25	−0.28	−0.30	−0.38
PACIFIC COAST																												
San Diego	+0.33	+0.42	+0.38	+0.41	+0.60	+0.53	+0.49	+0.47	+0.61	+0.31	+0.30	+0.50	+0.51	+0.32	+0.30	+0.26	+0.21	+0.28	+0.25	+0.13	0.00	+0.02	−0.01	−0.26	−0.12	−0.15	−0.17	−0.25
San Pedro	+0.31	+0.40	+0.36	+0.39	+0.58	+0.51	+0.47	+0.45	+0.59	+0.29	+0.28	+0.48	+0.49	+0.30	+0.28	+0.24	+0.19	+0.26	+0.23	+0.11	−0.02	0.00	−0.03	−0.28	−0.14	−0.17	−0.19	−0.27
San Francisco	+0.34	+0.43	+0.39	+0.42	+0.61	+0.54	+0.50	+0.48	+0.62	+0.32	+0.31	+0.51	+0.52	+0.33	+0.31	+0.27	+0.22	+0.29	+0.26	+0.14	+0.01	+0.03	0.00	−0.25	−0.11	−0.14	−0.16	−0.24
Fort Stevens	+0.59	+0.68	+0.64	+0.67	+0.86	+0.79	+0.75	+0.73	+0.87	+0.57	+0.56	+0.76	+0.77	+0.58	+0.56	+0.52	+0.47	+0.54	+0.51	+0.39	+0.26	+0.28	+0.25	0.00	+0.14	+0.11	+0.09	+0.01
Anacortes	+0.45	+0.54	+0.50	+0.53	+0.72	+0.65	+0.61	+0.59	+0.73	+0.43	+0.42	+0.62	+0.63	+0.44	+0.42	+0.38	+0.33	+0.40	+0.37	+0.25	+0.12	+0.14	+0.11	−0.14	0.00	−0.03	−0.05	−0.13
Seattle	+0.48	+0.57	+0.53	+0.56	+0.75	+0.68	+0.64	+0.62	+0.76	+0.46	+0.45	+0.65	+0.66	+0.47	+0.45	+0.41	+0.36	+0.43	+0.40	+0.28	+0.15	+0.17	+0.14	−0.11	+0.03	0.00	−0.02	−0.10
Vancouver	+0.50	+0.59	+0.55	+0.58	+0.77	+0.70	+0.66	+0.64	+0.78	+0.48	+0.47	+0.67	+0.68	+0.49	+0.47	+0.43	+0.38	+0.45	+0.42	+0.30	+0.17	+0.19	+0.16	−0.09	+0.05	+0.02	0.00	−0.08
Prince Rupert	+0.58	+0.67	+0.63	+0.66	+0.85	+0.78	+0.74	+0.72	+0.86	+0.56	+0.55	+0.75	+0.76	+0.57	+0.55	+0.51	+0.46	+0.53	+0.50	+0.38	+0.25	+0.27	+0.24	−0.01	+0.13	+0.10	+0.08	0.00

ACCURACY OF MEAN SEA LEVEL DETERMINATION

By PAUL SCHUREMAN, *Senior Mathematician, Division of Tides and Currents, United States Coast and Geodetic Survey*

Mean sea level is obtained by taking the average of the hourly heights of the sea over as long a period as practicable. Half-tide level, also known as mean-tide level, which is obtained from the high and low waters, is to be distinguished from mean sea level although approximating the same and having similar variations. The heights of the tide as originally observed are in general referred to a fixed tide staff, the zero of which is referred to near-by bench marks through spirit levels and the relation checked from time to time. An automatic tide gauge provides a means of obtaining a continuous record, this record being referred to the tide staff through daily comparisons.

Mean sea level as derived from different series of observations will usually differ by small amounts, this difference being caused mainly by actual variations in the level resulting from changing meteorological conditions. When two tide stations are so situated that meteorological conditions may be expected to have similar effects at both stations it is practicable to correct the sea level as obtained from a short series of tide observations at one of the stations by comparison with simultaneous observations at the other station, provided the mean sea level at the latter station has been well determined.

The purpose of this paper is to indicate the amount of dependence to be placed in a mean sea level determination as obtained from a limited series of observations. The work is based upon a comparison of results from a number of limited series of observations at several of our primary tide stations with the best determined mean sea level from all the observations at each of these stations. While a similar examination of variations in sea level determinations at other primary tide stations would be expected to give results differing to some extent, it is believed that the following tables will afford a measure of the dependence to be placed in a sea-level determination.

In these tests the results from Fort Hamilton, N. Y., Atlantic City, N. J., and San Francisco, Calif., were used. The observations at Fort Hamilton used in the test cover a period of 32 years (1893 to 1924), and the sea level adopted as a standard for the variations was a direct mean of the annual sea level for all of these years. The sea level for each month of the years 1893 to 1920 was derived in the usual manner from the hourly heights of the tide. The records for the years 1921 to 1924 were from observations by the United States Army Engineers and the mean sea level for each month was derived by applying the constant difference of 0.05 foot to the half-tide level as obtained from the high and low waters.

At Atlantic City the observations cover a period of 9 years (1912 to 1920) at the Million Dollar Pier, and 7 years (1923 to 1929) at the Atlantic City Steel Pier, making a total of 16 years. For this station the tests were made both with the means as derived directly from the observations and also with the means as corrected by comparison with simultaneous observations at Fort Hamilton. The corrected mean sea level from the entire series was used as the standard for the variations.

The observations at San Francisco cover a period of 32 years (1898 to 1929) and the mean sea level for the entire series was taken as the standard for the variations.

The tables which follow show the percentage of times the results from individual groups varied from the accepted standard within the limits indicated, and also give the mean and extreme variations for the different groups. The monthly and yearly means are for separate calendar months and years, but the groups of more than one year are made up of overlapping series beginning with the first of successive calendar years.

An examination of the table for Fort Hamilton indicates that sea level as derived from a single month of observations taken at random might possibly differ by nearly 1 foot from mean sea level as derived from the 32 years of observations, but will probably be correct within one-half foot about 92 per cent of the time. The mean variation is 0.23 foot. An accuracy of one-tenth of a foot in the monthly means occurred only 32 per cent of the time. This roughness in the determination of mean sea level from a single month of observations, when taken without correction, is due partly to seasonal fluctuation in the mean level and partly to yearly changes. As the seasonal fluctuation is such that a high or low level may be sustained for several consecutive months, the gain in the accuracy of the results by using several months of record in obtaining the mean would be small, but by using a full year the seasonal inequality is eliminated. At Fort Hamilton the maximum variation in the yearly means is 0.22 foot, and 69 per cent of the time the results are correct within one-tenth of a foot. The mean variation is 0.09 foot. There is a gain in accuracy as additional years of observations are included in the groups, and for the 19-year group all values are within 0.04 foot of the accepted mean.

Fort Hamilton, N. Y.—Percentage of variations in sea level determinations

[Based upon 32 years of observations]

Limits of variation from accepted mean	Length of group used in determination					
	1 month	1 year	3 years	5 years	10 years	19 years
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
+0.01 to −0.01 foot	5	6	13	14	13	36
+0.03 to −0.03 foot	10	25	23	50	52	79
+0.05 to −0.05 foot	16	34	40	57	78	100
+0.10 to −0.10 foot	32	69	77	86	100	
+0.20 to −0.20 foot	52	97	100	100		
+0.30 to −0.30 foot	72	100				
+0.50 to −0.50 foot	92					
	Foot	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*
Maximum variation	0.92	0.22	0.18	0.14	0.10	0.04
Mean variation	.23	.09	.07	.05	.04	.02

At San Francisco there is less seasonal fluctuation in the water level than there is at Fort Hamilton, and the maximum variation of the mean for a single month is 0.66 foot as compared with 0.92 foot for Fort Hamilton and a mean variation of 0.15 foot as compared with 0.23 foot for Fort Hamilton.

San Francisco, Calif.—Percentage of variations in sea-level determinations

[Based on 32 years of observations]

Limits of variation from accepted mean	Length of group used in determination					
	1 month	1 year	3 years	5 years	10 years	19 years
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
+0.01 to −0.01 foot	8	9	23	18	43	36
+0.03 to −0.03 foot	17	34	47	50	83	100
+0.05 to −0.05 foot	25	44	70	86	100	
+0.10 to −0.10 foot	45	72	90	100		
+0.20 to −0.20 foot	72	94	100			
+0.30 to −0.30 foot	92	100				
+0.50 to −0.50 foot	99					
	Foot	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*
Maximum variation	0.66	0.26	0.14	0.10	0.05	0.03
Mean variation	.15	.08	.05	.04	.02	.02

Atlantic City, N. J.—Percentage of variations in sea-level determinations

[Based on 16 years of observations]

Limits of variation from accepted mean	Means as directly obtained				Means corrected by comparison with Fort Hamilton observations			
	Length of group used				Length of group used			
	1 month	1 year	3 years	5 years	1 month	1 year	3 years	5 years
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
+0.01 to −0.01 foot	4	31	21	8	18	38	36	33
+0.03 to −0.03 foot	10	44	36	42	36	62	86	100
+0.05 to −0.05 foot	17	56	64	58	51	75	100	
+0.10 to −0.10 foot	33	75	86	100	78	100		
+0.20 to −0.20 foot	54	100	100		98			
+0.30 to −0.30 foot	73				100			
+0.50 to −0.50 foot	94							
	Foot	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*
Maximum variation	0.69	0.20	0.13	0.09	0.30	0.08	0.05	0.03
Mean variation	.21	.07	.05	.05	.07	.03	.02	.02

It will also be noted that at San Francisco 99 per cent of all monthly means come within one-half foot of the accepted mean as compared with 92 per cent for Fort Hamilton. While the results from the groups containing a year or more of observations do not differ much at the two stations, slightly better percentages are shown for San Francisco. This indicates that the level at San Francisco is less disturbed by meteorological changes than at Fort Hamilton.

At Atlantic City the uncorrected means show a percentage of variation comparable with that at the other two stations. After the means have been corrected by comparison with simultaneous observations at Fort Hamilton considerable improvement is noted, and we now find that the accuracy of the result from a single month of observations approximates that obtained from an entire year of observations not corrected. Also the corrected mean from a year of observations has a higher degree of accuracy than the uncorrected mean from 5 years and approximates to the accuracy attained from 10 years of observations at Fort Hamilton and San Francisco.

Hence it would appear that a mean which has been corrected by comparison with simultaneous observations may be expected to have a degree of accuracy approximating that of an uncorrected mean from a series of observations 10 times as long, provided, of course, that the two stations compared are so situated that the same meteorological conditions may be expected to have a similar effect on the sea level at both stations and also that the accepted sea level at the standard station used for the comparison has been accurately determined.

From an inspection of all the tables it will be noted that the means fall within the limits +0.01 to −0.01 only a small percentage of the time even for the longer groups, and the attainment of this degree of accuracy appears more or less accidental. It will also be noted that in some instances the percentages for the longer groups are less than those for shorter groups in the same limits. This, of course, must not be interpreted as indicating a less degree of precision in the longer group but should be considered as more or less accidental and resulting from the small number of means used in the tests.

GRAVITY AND ISOSTASY

By C. H. Swick, *Senior Mathematician, United States Coast and Geodetic Survey*

During the three years covered by this report the United States Coast and Geodetic Survey has made gravity determinations as follows: 9 stations in the Philippine Islands, 3 stations on the outlying rocks and islands near the northwest end of the Hawaiian Island group, and 13 stations in the West Indies. (See figs. 6 and 7.) In addition, a number of sea-gravity stations

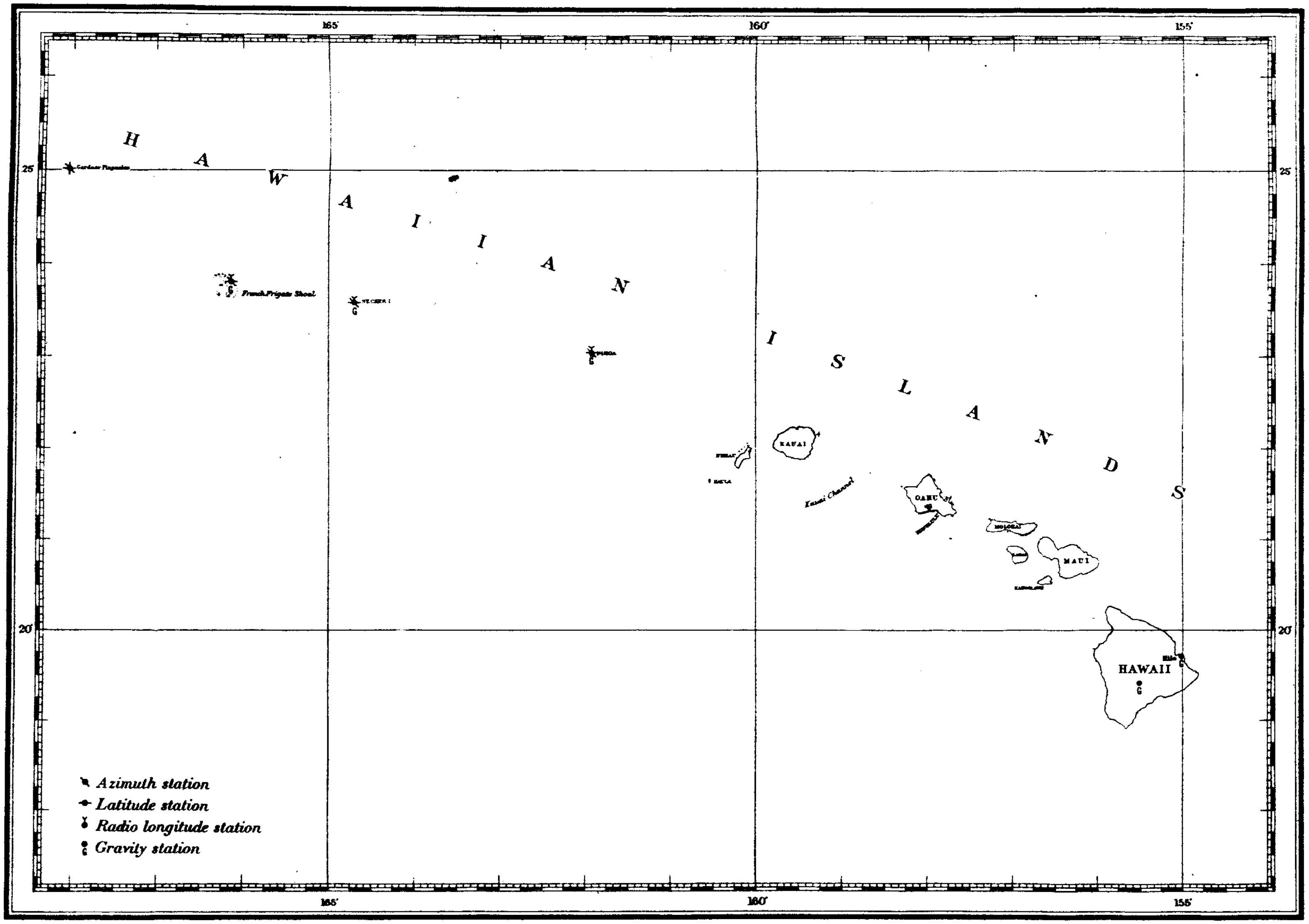


FIGURE 6.—Astronomical and gravity stations in Hawaiian Islands

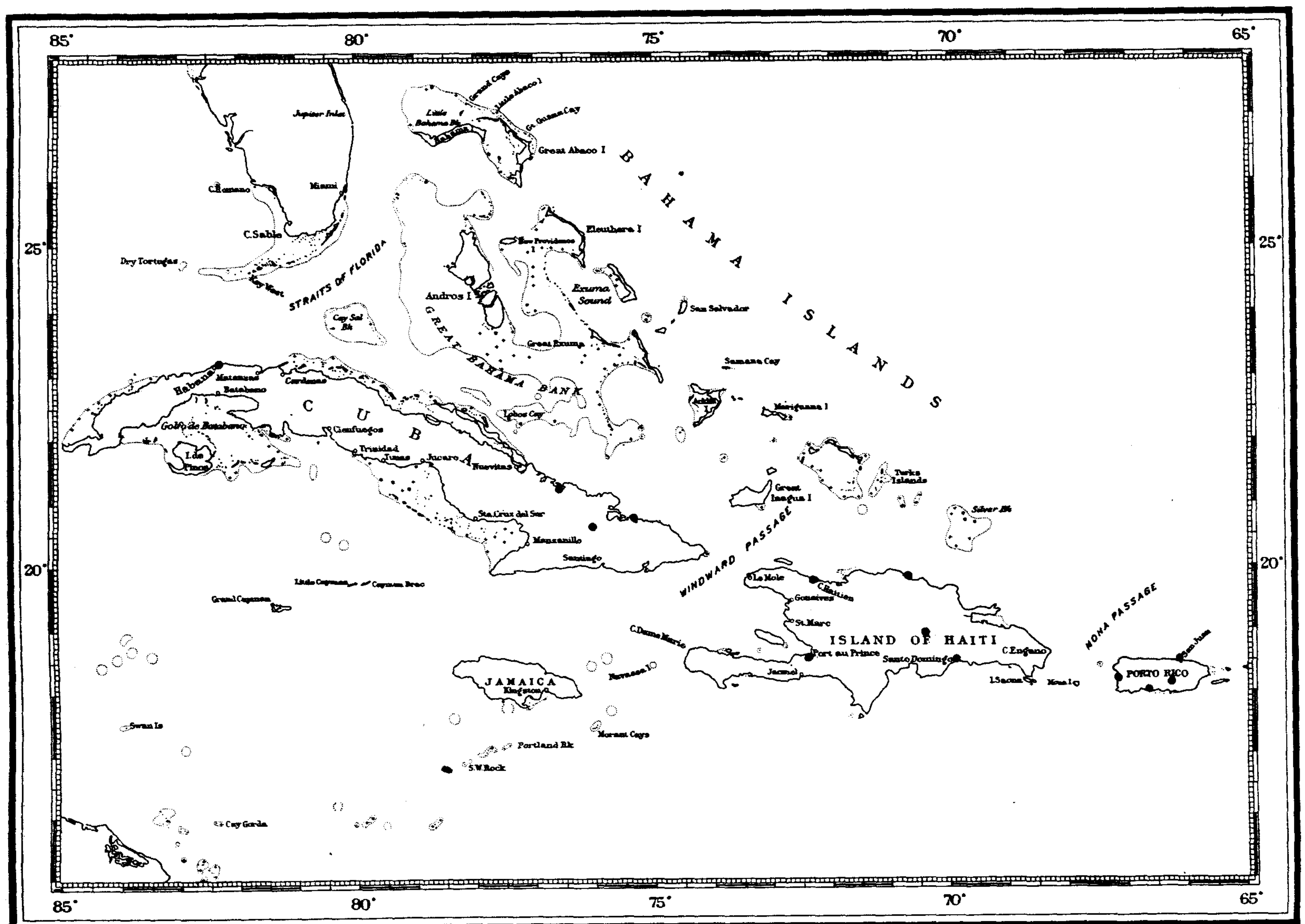


FIGURE 7.—Gravity stations in the West Indies

have been determined along the Atlantic coast by Dr. F. A. Vening Meinesz, of Holland, in cooperation with the United States Navy and the Carnegie Institution of Washington. A discussion of the work at sea will be found in another part of this report.

Owing to a discrepancy which occurred in the restandardization of the pendulums following the work in the Philippine Islands, the final values for the stations on those islands are not available. The following table (see fig. 8) contains the principal data for the Hawaiian stations and for all the stations in the West Indies except two for which the isostatic anomalies are still lacking. These two stations will be completed as soon as a million-scale map of Haiti and the adjacent regions now in press is available.

The gravity work in the West Indies was done to supplement the gravity-at-sea determinations made by Doctor Meinesz in the adjacent waters. It will be noted that in most cases the land and sea stations taken together form what might be termed gravity profiles north and south across the islands and the adjacent deeps. The results are of considerable interest on this account. This region has very rugged topography both above and below sea level and therefore is an interesting place for making tests of gravity and gravity theories.

The three Hawaiian stations also deserve special notice. They were determined with considerable difficulty in connection with a hydrographic survey of the region. They are on outlying reefs and islands several hundred miles from the nearest inhabited islands. According to geologists, they are at the opposite end from the most recently formed islands of the archipelago and so are on the oldest islands, which are now supposed to be sinking. It can be seen from the table that the isostatic anomalies exhibit the same tendency to be positive as at other Hawaiian gravity stations, although to a somewhat less marked degree.

GRAVITY EXPEDITION OF THE UNITED STATES NAVY IN 1928

By Eleanor A. Lamson, *Associate Astronomer, United States Naval Observatory*

Although many attempts had been made to develop a type of apparatus with which gravity determinations could be made at sea, it was not until Dr. F. A. Vening Meinesz, of the Netherlands Geodetic Commission, devised his very ingenious 3-pendulum gravity apparatus that maritime gravity survey was put on a practicable basis. (See Theory and Practice of Pendulum Observations at Sea, by F. A. Vening Meinesz, publication of the Netherlands Geodetic Commission, 1929.)

After having demonstrated the value of his method by an extensive series of observations on board Dutch submarines in the Mediterranean and in the Indian, Atlantic, and Pacific Oceans during the years 1923 to 1927, Doctor Meinesz accepted the invitation extended to him by the Carnegie Institution of Washington in 1928 to visit the United States with his apparatus and to cooperate with the United States Navy in making a gravity survey in the Gulf of Mexico and in the Caribbean Sea.

For this purpose the Secretary of the Navy authorized the Superintendent of the United States Naval Observatory to make the necessary arrangements. The United States submarine *S–21*, in which the gravity apparatus was installed, and the Eagle boats *No. 35* and *No. 58* were detailed for the work. Lieut. T. L. Nash, United States Navy, commanding the Eagle boat *No. 35*, was in command of the expedition, while Lieut. J. L. Fisher, United States Navy, was in command of the *S–21*. The cooperating scientists on board the submarine were Dr. F. A. Vening Meinesz, of the Netherlands Geodetic Commission; Dr. F. E. Wright, of the Geophysical Laboratory of the Carnegie Institution of Washington; and E. B. Collins, of the Hydrographic Office of the Navy Department.

A description of the gravity apparatus with theoretical considerations, an account of the survey made by the expedition, together with a discussion of the results obtained, will appear shortly in Appendix I, Volume XIII, Publications of the United States Naval Observatory, second series, now in the hands of the printer.

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
Form 650
Ed. Oct., 1929

PRINCIPAL FACTS AT GRAVITY STATIONS

(VALUES ARE BASED ON POTSDAM SYSTEM)

Helmert formula of 1901, $\gamma_o = 978.030[1+0.005302 \sin^2\phi - 0.000007 \sin^2 2\phi$

Bowie formula of 1917. $\gamma_o = 978.039[1+0.005294 \sin^2\phi - 0.000007 \sin^2 2\phi$

Station		Latitude	Longitude	Elevation	Observed gravity	Correction for		Gravity (Helmert)		Anomaly (Helmert)		Gravity (Bowie)		Anomaly (Bowie)	
No.	Name	ϕ	λ		g	Elevation	Topography and compensation	Theoretical γ_o	Computed g_o	Free-air $g-\gamma_o''$	Isostatic $g-g_o$	Theoretical γ_o	Computed g_o	Free-air $g-\gamma_o''$	Isostatic $g-g_o$
				Meters	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²
	Hawaiian Islands														
	East Island	23 47.0	166 12.5	2	979.196	-0.001	+0.206	978.870	979.075	+0.327	+0.121	978.878	979.083	+0.319	+0.113
	Nihoa	23 03.5	161 55.4	15	979.104	- .005	+ .210	978.822	979.027	+ .287	+ .077	978.830	979.035	+ .279	+ .069
	Necker	23 34.7	164 42.4	30	979.154	- .009	+ .210	978.856	979.057	+ .307	+ .097	978.864	979.065	+ .299	+ .089
	West Indies Islands														
	San Juan, P.R.	18 28.2	66 06.3	8	978.671	-0.002	+0.148	978.548	978.694	+0.125	-0.023	978.556	978.702	+0.117	-0.031
	Aibonita, P.R.	18 07.8	66 16.0	648	978.563	- .200	+ .188	978.530	978.518	+ .233	+ .045	978.538	978.526	+ .225	+ .037
	Ponce, P.R.	18 00.5	66 37.2	14	978.623	- .004	+ .130	978.523	978.649	+ .104	- .026	978.531	978.657	+ .096	- .034
	Mayaguez, P.R.	18 12.1	67 08.7	16	978.664	- .005	+ .134	978.534	978.663	+ .135	+ .001	978.542	978.671	+ .127	- .007
	Santo Domingo, D.R.	18 27.8	69 53.3	8	978.649	- .002	+ .081	978.548	978.627	+ .103	+ .022	978.556	978.635	+ .095	+ .014
	Bonao, D.R.	18 56.2	70 24.6	172	978.597	- .053	+ .063	972.574	978.584	+ .076	+ .013	978.582	978.592	+ .068	+ .005
	Puerto Plata, D.R.	19 48.2	70 41.4	4	978.626	- .001	+ .084	978.622	978.705	+ .005	- .079	978.630	978.713	- .003	- .087
	Cape Haitian, H.	19 46.1	72 12.7	11	978.713	- .003		978.620		+ .096		978.628		+ .088	
	Port au Prince, H.	18 33.8	72 20.2	4	978.596	- .001		978.553		+ .044		978.561		+ .036	
	Alto Cedro, C.	20 35.9	75 57.6	76	978.784	- .023	+ .065	978.669	978.711	+ .138	+ .073	978.677	978.719	+ .130	+ .065
	Cayo Mambi, C.	20 40.6	75 16.3	15	978.820	- .005	+ .070	978.674	978.739	+ .151	+ .081	978.682	978.747	+ .143	+ .073
	Chaparra, C.	21 10.1	76 29.3	13	978.721	- .004	+ .062	978.703	978.761	+ .022	- .040	978.711	978.769	+ .014	- .048
	Habana, C.	23 08.5	82 22.4	38	978.845	- .012	+ .068	978.827	978.873	+ .030	- .028	978.835	978.881	+ .022	- .036

FIGURE 8.—Anomalies and other data for gravity stations in Hawaiian Islands and West Indies

Preliminary reports of the survey have been made by Doctor Meinesz in Nature, No. 3099, vol. 123, entitled "Gravity Expedition of the U. S. Navy," and in Proceedings of the Royal Academy, Amsterdam, Vol. XXXII, 1929, "A Gravity Expedition of the U. S. Navy." A lecture entitled "The Gravity Measurement Cruise of the U. S. S. *S-21*" was delivered by Capt. C. S. Freeman, United States Navy, before the American Geophysical Union, Washington, D. C., April, 1929.

A brief synopsis of the work of the expedition follows: The survey party left Washington October 1, 1928, for Hampton Roads; thence cruised southward around Cape Hatteras, down the Atlantic coast to Key West. From Key West they steamed westward into the Gulf of Mexico, crossing the Sigsbee Deep; thence northwest to Galveston. From Galveston the course was followed via the Mississippi Delta back to Key West. Continuing along the coast of Cuba to Guantanamo, the vessels cruised over a part of the Bartlett Deep southeast of the island. From Guantanamo the expedition reached St. Thomas via the Nares Deep; thence back to Guantanamo, sweeping widely to the southward. From Guantanamo the survey party sailed almost due north for Hampton Roads; thence to Washington, which was reached November 27, 1928. Throughout the voyage 49 sea stations were occupied.

In planning the itinerary of the cruise it was the intention to include as many stations as possible which would assist in solving the geophysical and geological problems in and near the West Indies. Although the apparatus, hung in gimbals, was mounted in the central control room of the submarine and consequently could be used even when the rolling and pitching were fairly large, the sea was so rough on the return voyage that a number of observations planned for the top and the bottom of the continental slope could not be made. In other respects the original plans were followed.

The base station adopted for the work is that of the United States Coast and Geodetic Survey in Washington. For this reason base observations were made with the apparatus in the gravity base station at Washington before and after the expedition. Before and after the voyage base observations were also made with the apparatus in the Netherlands gravity base station, De Bilt, which may serve in the future to check the Washington station with the international base station, Potsdam.

The results of the gravity observations were provisionally computed for the larger number of sea stations during the voyage, and at the same time the isostatic reductions for these stations were made at the United States Coast and Geodetic Survey in Washington. Consequently, the preliminary results were available for discussion shortly after the return of the scientists to Washington.

In addition to the pendulum observations for gravity determinations, a continuous series of soundings for the entire voyage was made on the submarine with the sonic depth finder of the United States Navy, both at the surface of the sea and also when the *S-21* was submerged.

The final computations for the gravity work have been made at the United States Naval Observatory, and from the results, together with the isostatic reductions for the gravity sea stations kindly furnished by the United States Coast and Geodetic Survey, Doctor Meinesz and Doctor Wright have made the discussion which appears in the Naval Observatory publication, as heretofore noted.

The data pertaining to the expedition are listed in the following table:

Principal facts for gravity stations at sea

[Washington as base: T=0.5015438, g=980.112 dynes. Observations made on the U. S. submarine S-21 (Oct. 3-Nov. 25, 1928)]

No. of station	Depth	Latitude (N.) ϕ	Longitude (W.) λ	Correction for topography and compensation	Observed gravity at station g	Helmert formula: Theoretical gravity γ	Helmert formula: Computed gravity g_c	Helmert formula: Anomaly g_c-g	Bowie formula: Theoretical gravity γ	Bowie formula: Computed gravity g_c	Bowie formula: Isostatic anomaly $g-g_c$	Bowie formula: Free-air anomaly $g-\gamma$
	Fathoms	° ′	° ′	*Cm./sec.*[2]	*Cm./sec.*[2]	*Cm./sec.*[2]	*Cm./sec.*[2]	*Cm./sec.*[2]	*Cm./sec.*[2]	*Cm./sec.*[2]	*Cm./sec.*[2]	*Cm./sec.*[2]
1 (Hampton Roads)		36 56.7	76 19.9	+0.020	979.874	979.897	979.917	−0.043	979.903	979.923	−0.049	−0.029
2	15	32 03.6	79 58.0	+0.018	979.511	979.486	979.504	+0.007	979.492	979.510	+0.001	+0.019
3	26	28 20.5	80 05.5	+0.029	979.235	979.194	979.223	+0.012	979.201	979.230	+0.005	+0.034
4	37	24 53.5	80 29.6	+0.031	978.980	978.945	978.976	+0.004	978.952	978.983	−0.003	+0.028
5	210	24 52.0	84 07.0	+0.057	979.022	978.943	979.000	+0.022	978.950	979.007	+0.015	+0.072
6	1,867	24 47.0	84 27.0	−0.079	978.867	978.937	978.858	+0.009	978.945	978.866	+0.001	−0.078
7	1,823	24 45.0	86 05.0	−0.042	978.970	978.935	978.893	+0.077	978.942	978.900	+0.070	+0.028
8	1,900	25 06.7	89 22.0	−0.036	978.948	978.960	978.924	+0.024	978.967	978.931	+0.017	−0.019
9	1,925	24 59.7	90 36.2	−0.034	978.988	978.952	978.918	+0.070	978.960	978.926	+0.062	+0.028
10	1,993	25 01.3	93 22.5	−0.041	979.000	978.954	978.913	+0.087	978.961	978.920	+0.080	+0.039
11	907	26 24.0	93 45.2	+0.004	979.102	979.051	979.055	+0.047	979.058	979.062	+0.040	+0.044
12	73	28 05.0	92 05.5	+0.025	979.228	979.174	979.199	+0.029	979.181	979.206	+0.022	+0.047
13	1,021	27 21.7	89 05.0	−0.002	979.156	979.121	979.119	+0.037	979.128	979.126	+0.030	+0.028
14	535	28 15.0	89 11.0	+0.007	979.216	979.187	979.194	+0.022	979.194	979.201	+0.015	+0.022
15	530	28 46.3	88 44.5	−0.003	979.247	979.226	979.223	+0.024	979.234	979.231	+0.016	+0.013
16	1,220	28 20.0	87 55.5	−0.034	979.153	979.193	979.159	−0.006	979.200	979.166	−0.013	−0.047
17	1,727	26 52.0	86 17.5	−0.042	979.112	979.084	979.042	+0.070	979.092	979.050	+0.062	+0.020
18	1,815	26 08.5	85 29.0	−0.054	979.018	979.032	978.978	+0.040	979.040	978.986	+0.032	−0.022
Key West				+0.035	978.964							
Galveston				+0.007	979.274							
19	1,332	21 33.5	76 16.0	−0.063	978.627	978.727	978.664	−0.037	978.735	978.672	−0.045	−0.108
20	1,470	21 08.3	74 59.3	−0.044	978.630	978.701	978.657	−0.027	978.709	978.665	−0.035	−0.079
21	1,582	19 12.5	75 52.5	−0.028	978.564	978.588	978.560	+0.004	978.596	978.568	−0.004	−0.032
22	2,867	19 30.5	75 53.0	−0.136	978.421	978.606	978.470	−0.049	978.614	978.478	−0.057	−0.193
23 (Moro Castle)		19 57.4	75 52.5	+0.087	978.742	978.631	978.718	+0.024	978.639	978.726	+0.016	+0.103
24	2,530	19 18.0	76 45.5	−0.109	978.522	978.594	978.485	+0.037	978.602	978.493	+0.029	−0.080
25	3,770	19 36.5	76 51.0	−0.208	978.432	978.612	978.404	+0.028	978.620	978.412	+0.020	−0.188
26	942	19 53.3	76 51.0	−0.010	978.680	978.627	978.617	+0.063	978.635	978.625	+0.055	+0.045
27 (Guantanamo)	5	19 54.5	75 08.9	+0.085	978.742	978.628	978.713	+0.029	978.636	978.721	+0.021	+0.106
28	2,205	20 27.0	72 26.7	−0.096	978.458	978.660	978.564	−0.106	978.668	978.572	−0.114	−0.210
29	2,257	20 24.0	71 21.5	−0.095	978.461	978.657	978.562	−0.101	978.665	978.570	−0.109	−0.204
30	2,520	19 32.5	68 35.0	−0.069	978.382	978.608	978.539	−0.157	978.616	978.547	−0.165	−0.234
31	4,300	19 38.0	67 45.8	−0.176	978.342	978.613	978.437	−0.095	978.621	978.445	−0.103	−0.279
32	2,540	20 13.0	67 46.0	−0.012	978.670	978.646	978.634	+0.036	978.655	978.643	+0.027	+0.015
33	2,800	22 09.5	67 35.0	−0.004	978.783	978.764	978.760	+0.023	978.772	978.768	+0.015	+0.011
34	3,045	21 48.5	66 30.3	−0.017	978.736	978.742	978.725	+0.011	978.750	978.733	+0.003	−0.014
35	2,920	20 35.0	66 25.5	−0.010	978.701	978.668	978.658	+0.043	978.676	978.666	+0.035	+0.025
36	4,210	19 46.5	66 14.0	−0.139	978.369	978.621	978.482	−0.113	978.629	978.490	−0.121	−0.260
37 (San Juan)	5	18 27.8	66 06.8	+0.148	978.689	978.548	978.696	−0.007	978.556	978.704	−0.015	+0.133
38 (St. Thomas)	5	18 20.0	64 56.0	+0.141	978.687	978.541	978.682	+0.005	978.549	978.690	−0.003	+0.138
39	2,367	17 55.5	65 06.0	−0.066	978.398	978.519	978.453	−0.055	978.527	978.461	−0.063	−0.129
40	970	17 37.5	65 13.3	+0.058	978.557	978.503	978.561	−0.004	978.512	978.570	−0.013	+0.045
41	2,517	15 47.0	67 43.0	−0.029	978.436	978.412	978.383	+0.053	978.421	978.392	+0.044	+0.015
42	1,652	16 18.0	71 48.7	+0.006	978.473	978.436	978.442	+0.031	978.444	978.450	+0.023	+0.029
43	2,296	16 50.0	73 04.8	−0.052	978.471	978.463	978.411	+0.060	978.471	978.419	+0.052	0.000
44	1,737	18 45.8	73 26.0	−0.051	978.554	978.564	978.513	+0.041	978.571	978.521	+0.033	−0.017
45	1,100	19 57.0	74 31.0	−0.010	978.618	978.631	978.621	−0.003	978.639	978.629	−0.011	−0.021
46	952	22 56.5	74 26.8	+0.029	978.818	978.814	978.843	−0.025	978.822	978.851	−0.033	−0.004
47	2,512	23 31.8	73 59.5	−0.056	978.804	978.853	978.797	+0.007	978.861	978.805	−0.001	−0.057
48	2,512	26 16.5	74 00.0	−0.010	979.054	979.042	979.032	+0.022	979.050	979.040	+0.014	+0.004
49	2,562	32 27.0	74 12.0	−0.031	979.482	979.517	979.486	−0.004	979.524	979.493	−0.011	−0.042

GRAVITATIONAL WORK AT THE BUREAU OF STANDARDS

By PAUL R. HEYL, *Chief of the Sound Section, United States Bureau of Standards*

The Bureau of Standards, at the request of the United States Coast and Geodetic Survey, has undertaken an absolute determination of gravity at Washington. There has never been made in this country any determination of this nature which can qualify as a precision measurement according to modern standards. The Potsdam determination of 25 years ago has been the ultimate standard of reference for gravity work in the United States.

The Bureau of Standards determination has been under way for something over a year. The preliminary study of the subject has been finished and experimental work has begun. The first point to be studied experimentally is the Helmert-Potsdam formula for the bending correction. This correction was a considerable factor in the Potsdam determination, amounting in certain cases to five parts in a million, and its validity has rested up to the present on a purely theoretical basis. An experimental check of this formula is now in progress.

The Bureau of Standards has recently completed a redetermination of the constant of gravitation, lasting about five years. The heretofore accepted value of this constant has been 6.66×10^{-8} in c. g. s. units, as determined by the work of Boys and of Braun, published about 35 years ago. While the computations are not quite complete at this time of writing (January 15), it may be said that the mean value so far obtained is 6.669, and that this can hardly be altered by more than one unit of the third decimal place by the results yet to be computed.

This work was done by the torsion balance *in vacuo*, using the time of swing method. The large attracting masses were of steel, of about 60 kg each. The moving system had a radius of 10 cm and carried small masses of about 50 g each. The time of swing in the near position of the large masses was about 28 minutes and in the far position 33½ minutes, a difference of about 330 seconds. The corresponding difference in Braun's experiments was 46 seconds.

TRIANGULATION, TRAVERSE, AND LEVELING BY THE UNITED STATES GEOLOGICAL SURVEY

By George Otis Smith, *Director, United States Geological Survey*

The control work which the United States Geological Survey does is for use in its topographic surveys and is of third-order accuracy, as defined by the Board of Surveys and Maps. Some first and second order levels are run, but only when level control must be projected into unsurveyed areas.

During the calendar years 1927, 1928, and 1929 control work was carried on in 36 States and in Hawaii. During that period 585 triangulation stations were occupied and marked; 13,882 miles of transit traverse and 21,627 miles of levels were run. Permanent marks were established approximately every 3 miles along transit traverse and level routes. The geodetic coordinates of many described intermediate points of transit-traverse lines were computed, and numerous intermediate bench marks were established along level routes. All tapes and rods used on control surveys were carefully calibrated each season.

Section E (topographic mapping) and section F (map compilation from aerial photographs) of the new manual of topographic instructions, United States Geological Survey Bulletin 788, and the same bulletin, combining the several sections in a single volume, were published in 1928. The combined publication contains 419 pages of text and numerous illustrations describing instruments and methods now in use by the Geological Survey in extending control and topographic surveys and in map compilation from aerial photographs.

Instructions for First-Order Leveling, written by C. H. Birdseye, was published in mimeographed form in 1929. Formulas and Tables for the Construction of Polyconic Projections, United States Geological Survey Bulletin 809, compiled by C. H. Birdseye, was also published in 1929. Bulletin 809 contains 42 pages of descriptive and explanatory matter, projection tables with the coordinates given in inches for map scales of 1:24,000, 1:31,680, 1:48,000, and 1:96,000, a table of coordinates for the modified polyconic projection of the map of the world on the natural scale in meters, and a table of coordinates for the modified polyconic projection of the map of the world on the 1:1,000,000 scale in inches. Additional polyconic projection tables, with the coordinates given in inches, for the map scales 1:10,000, 1:12,000, 1:20,000, 1:62,500, 1:63,360, and 1:125,000, and a table for the projection of large areas, on the natural scale, with the coordinates given in meters, have been prepared but have not been published.

Aerial photography is constantly increasing in importance as a factor and aid in topographic mapping. There is an ever-increasing demand for detail and accuracy in topographic maps which can be supplied by the proper use of the planimetric details shown in good aerial photographs. Photographs made with the multiple-lens and with the single-lens types of aerial cameras each have particular value, depending on the type and inaccessibility of the area to be mapped, the amount and location of control available for their adjustment, and the amount of detail which it is desired to show in the topographic map. During the 3-year period, 1927 to 1929 inclusive, approximately 23,900 square miles in the United States proper and 12,750 square miles in Alaska were photographed for the Geological Survey and its cooperating agencies.

GEODETIC WORK BY CORPS OF ENGINEERS, UNITED STATES ARMY

By Major General Lytle Brown, *Chief of Engineers, United States Army*

The control established by the Corps of Engineers, United States Army, for use in military topographic mapping where such is being prosecuted, is classed as third order under the control standards adopted by the Board of Surveys and Maps of the Federal Government. Since January 1, 1927, control for military topographic mapping has been executed in connection with tactical mapping in Virginia and Texas and in the survey of a number of isolated military training areas for the construction of fire-control or training maps. In addition to this work in the United States control has been established for military mapping in Luzon, Philippine Islands, and in the Panama Canal Zone and vicinity. This control has consisted of triangulation, traverse, and leveling, as the circumstances required. In the island of Oahu, Hawaii, the Corps of Engineers cooperated with the United States Coast and Geodetic Survey and the United States Geological Survey in establishing new horizontal and vertical control nets for that island.

In connection with its civil functions of river and harbor improvement and flood control the Corps of Engineers does geodetic work in many sections of the country. Most of this work is subordinate to the normal river and harbor improvement projects, is of use mainly in connection with these projects, and instances of it are too numerous to cite in detail. That of the United States Lake Survey at Detroit, Mich., and that of the Mississippi River Commission should, however, be noted.

First-order triangulation on the Great Lakes as contemplated by the existing project was finished in 1922. The arcs completed since 1902 have been adjusted to positions of stations in the 1902 general adjustment. Observational data of the later work have recently been furnished to the United States Coast and Geodetic Survey to be used in a general readjustment of triangulation in the eastern part of the United States.

The Lake Survey has executed no new systems of second or third order triangulation during the last three years. Some few additional control points, mostly temporary, have been established for locations of topographic and hydrographic surveys.

Reestablishment of geodetic control on Lake Champlain has been undertaken. In connection with other work in 1928 and 1929 existing triangulation stations north of Burlington, Vt., were recovered and remarked, and new stations were established and located to replace missing stations.

No new lines of leveling were run during the last three years. A number of new bench marks were established along the St. Clair River and their elevations determined by first-order leveling methods from existing bench marks of 1898.

Continuous graphic records of water levels on the Great Lakes and connecting rivers are being obtained at the following stations:

Marquette, Mich.
Mackinaw City, Mich.
Milwaukee, Wis.
Harbor Beach, Mich.
Port Huron, Mich. (two).
Roberts Landing, Mich.
St. Clair Flats, Mich.
Fort Wayne, Detroit, Mich.
Cleveland, Ohio.
Buffalo, N. Y.
Cape Vincent, N. Y.

Staff gages are being read three times daily at Windmill Point, Detroit, Mich., and at Oswego, N. Y. Records of automatic gages at Sault Ste. Marie, Mich. (two), Calumet Harbor, Ill., and Amherstburg, Ontario, and of staff gages at Duluth, Minn., and Houghton, Mich., are being furnished to the Lake Survey from other engineer districts on the Lakes.

The records of the various gages are the basis for determining the causes and extent of fluctuations of lake levels, changes in regimen of interlake and outflow rivers, effect on lake levels of diversions through artificial outlets, etc. They also afford means of determining the direction and rate of tilt of the earth's surface in the lake region. A recent study of the latter subject indicates that the movement is general throughout the lake basin, that the axis of tilt is about 20° north of west, that the average rate on Lakes Michigan, Huron, and Erie normal to this axis is about 6 inches in 100 miles in 100 years, and that the rate in the Lake Superior Basin is about double and in the Ontario Basin about three times as great as in the Michigan-Huron-Erie Basins. The relative movement is upward to the north and east.

Under the jurisdiction of the Mississippi River Commission, triangulation was executed under a cooperative agreement between the Corps of Engineers and the United States Coast and Geodetic Survey for an arc of first-order triangulation along the Mississippi River from New Orleans, La., to St. Louis, Mo. This work was proposed to supplement the existing first-order network of triangulation, the work being in the interests of general surveying and mapping and to be used also for the reduction to North American datum of all triangulation stations previously established in this area. Connections will be made to the existing system at intervals of about 15 miles and will make possible a ready and correct adjustment of all previous control along this stretch of the Mississippi River.

In the Memphis (Tenn.) district, under the Mississippi River Commission, a traverse along the eastern rim of the alluvial valley of the Mississippi River from about latitude 35° to 37° 15′ is in progress, and about 125 miles have been completed with a third-order accuracy from latitude 36° northward. A levee alignment third-order traverse along the west bank of the Mississippi River from latitude 34° to 37° 08′ and along the east bank from 34° 07′ to 35° and from 36° 30′ northward about 20 miles has just been completed, totaling about 460 miles. The checking of the field work and the computation of positions for publication for this work have just been commenced, and at present there are no positions available for publication.

In the Vicksburg (Miss.) district the geodetic work executed consists of surveys made by the United States Geological Survey under the direction of the district office on the Tallahatchie, Coldwater, Little Tallahatchie, Scoona, and Yazoo Rivers, together with work done by the district on the low-water survey of the Mississippi River and on the survey operations carried on for the location of levees in the Boeuf Basin Floodway. On this work 1,328 miles of third-order traverse and 841 miles of third-order levels were run and 272 permanent marks established.

In the New Orleans district of the Mississippi River Commission 318 miles of first-order levels were run, and a closed circuit extending from Baton Rouge, La., to Melville, La., Simmesport, La., Red River Landing, and thence back to Baton Rouge was completed. On this work 43 new bench marks were established and 83 old marks connected with. A low-water survey of the Mississippi River between Vicksburg, Miss., and Baton Rouge, La., is in progress. Control for this work has been established by means of a system of third-order triangulation supplemented by a taped traverse along the levee on the right bank and a second taped traverse along the foot of the bluffs on the left bank of the Mississippi River. These control systems have been connected with the existing Mississippi River Commission control at intervals of 10 miles or less. New metal bench marks have been established at intervals of about 1 mile on the right bank control line and at intervals of about 3 miles on the left bank.

In addition to the above work the Mississippi River Commission has maintained an automatic tide gage near Biloxi, Miss., on the Gulf of Mexico.

GEODETIC WORK OF THE INTERNATIONAL BOUNDARY COMMISSION, UNITED STATES-ALASKA AND CANADA

By R. N. Ashmun, *Senior Mathematician, International Boundary Commission, United States-Alaska and Canada*

During the 3-year period January 1, 1927, to December 31, 1929, the International Boundary Commission, United States-Alaska and Canada, has prepared for publication the description of that part of the international boundary between the United States and Canada which extends from the northwesternmost point of Lake of the Woods to Lake Superior. The final report of the commission on this portion of the boundary will contain the geographic positions of about 5,000 stations, all on the North American datum of 1927, the description of the line being set forth in tabular form. These geographic positions comprise about 1,800 boundary turning points located in waterways and the necessary traverse stations, triangulation stations, and reference monuments which form the network of the geodetic control.

The boundary line is controlled by first-order triangulation and traverse executed by the United States Coast and Geodetic Survey, the Geodetic Survey of Canada, and the United States Lake Survey. The boundary triangulation controlled by this first-order triangulation and traverse consists of a scheme of major triangulation which in turn controls the minor triangulation that straddles the boundary lakes and rivers. From this triangulation the geographic positions of the above-mentioned boundary points have been determined.

In the adjustment of this triangulation the work was broken into many nets, the largest of which necessitated the solution of about 117 equations, in which all inconsistencies were distributed by the method of least squares.

The sites of the reference monuments are so located that the positions of the boundary turning points in the water can be readily determined from them. These turning points of the boundary were so chosen by the International Boundary Commissioners that they would conform with the provisions of the treaty of 1908 between the United States and Great Britain and the treaty of 1925 between the United States and Great Britain in respect of Canada. The reference monuments are, where practicable, set in pairs so that, in general, each turning point falls on line between two reference monuments.

The commission has determined by geodetic surveys and marked by bronze tablets the exact location of the international boundary line on 11 of the principal bridges and tunnels between the United States and Canada.

The boundary across each of these bridges and tunnels is a straight-line course joining two turning points in the water. The geographic position of the intersection of the boundary line and each bridge or tunnel was determined by angular and linear measurements from reference monuments and triangulation stations along the adjacent shores.

TRIANGULATION IN HAWAII

By Hugh C. Mitchell, *Senior Mathematician, United States Coast and Geodetic Survey*

In 1899 the Hawaiian Islands were annexed to the United States and during the next year they were given the status of a Territory—which status they still maintain. The Coast and Geodetic Survey, being charged with the charting of domestic waters and of control surveys in domestic territory, immediately took up the survey of the islands. At first survey parties were sent to the islands only infrequently, but more recently greater activity in hydrographic and land surveying has been maintained.

The islands themselves had been almost completely covered with triangulation prior to 1890, in the days of the Kingdom of Hawaii. Such surveys were required to control the cadastral surveys made for title records when, with the inauguration of a constitutional form of government, land ownership passed from a feudal type of tenure to individual (fee simple) ownership.

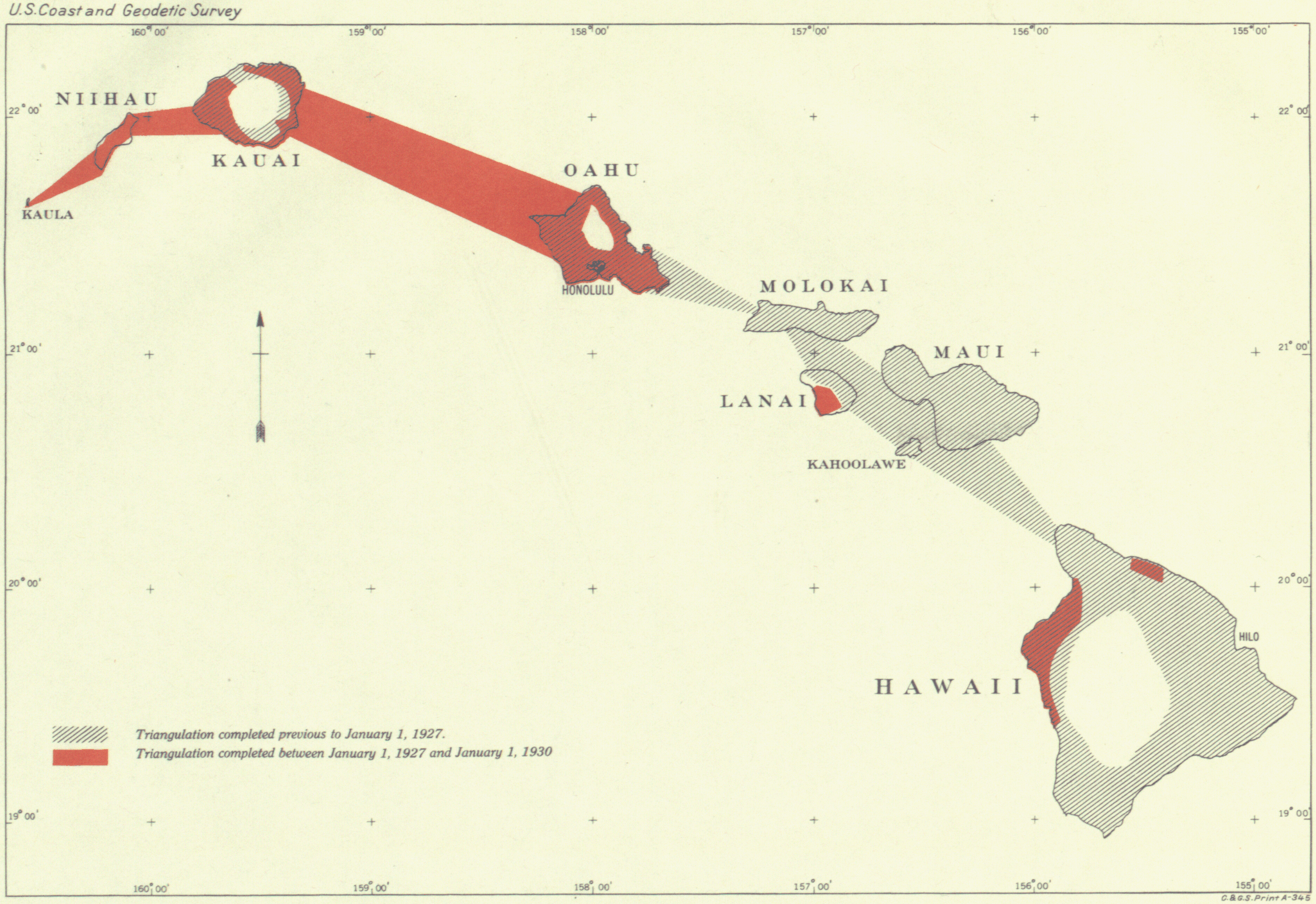


FIG. 9 – TRIANGULATION IN THE HAWAIIAN ISLANDS.

In order to correlate and coordinate these older surveys, both among themselves and with the more modern surveys made by the Coast and Geodetic Survey, a congressional appropriation was made in 1924 and continued through several years providing for a complete adjustment and computation of the triangulation of the islands. This work was completed in 1929 and the results are contained in Special Publication No. 156, entitled "Triangulation in Hawaii." The geodetic positions of about 1,330 triangulation stations and the descriptions of about half of these, which are all that are available, are given in the publication. The positions are all on one datum which is based on an astronomical longitude at Honolulu and on several astronomical latitudes scattered over the various islands and which because of its history is known as the Old Hawaiian datum. (See fig. 9.)

In addition to a considerable amount of detailed horizontal control surveys executed during the past three years in many parts of the islands for hydrographic and topographic purposes, a complete new triangulation of the island of Oahu has been made at the instance of other Federal organizations and the Territorial Survey of Hawaii and in cooperation with them. Although executed under instructions for second-order work, this new triangulation approaches first-order accuracy. This survey is being used for varied and important purposes such as the control of adjacent hydrographic charts, the control of the standard topographic map and special maps for military purposes, the location of lighthouses and of other aids to navigation, and, by no means least in value, the control of cadastral surveys. The territorial government, in order to protect the stations of this survey and to facilitate their use by surveyors and engineers, has placed over them special combination signals of a permanent character. Most of these signals have an elevated observing platform of concrete and a demountable signal pole.

Another important piece of geodetic work in the islands was the connection of the triangulation schemes of the islands of Oahu and Kauai. An unsuccessful attempt was made in 1910 to effect this connection. It was accomplished in 1928 in spite of great difficulties. There were many days of rain and hazy atmosphere, the sides of the triangles had lengths as great as 95 statute miles, and the higher mountain peaks on which the stations were located were almost continuously enshrouded in clouds.

Other work accomplished during the past three years includes astronomical determinations on a number of the small uninhabited rocks and islands which occur at infrequent intervals for hundreds of miles northwest of the main group of islands and an extensive triangulation scheme covering the French Frigate Shoals.

MAP PROJECTIONS

By OSCAR S. ADAMS, *Senior Mathematician, United States Coast and Geodetic Survey*

During the period of the past three years interest in map construction and map projections has continued to exist even in a greater degree than formerly. The need for special maps for aerial navigation has tended to this end. In general, two types of projection are considered for these maps, either the conformal or the equal-area projection.

The United States Coast and Geodetic Survey has published two pamphlets dealing directly with projections and has also issued a revised edition of another projection publication during this period. Some time ago the Board of Surveys and Maps of the Federal Government adopted the Albers projection for the general map of the United States. Since no table of coordinates for such a map had been computed, a table was prepared at the request of the United States Geological Survey and published as Special Publication No. 130 under the title Tables for Albers Projection. In Special Publication No. 153 is contained a development and computation of a Conformal Projection of the Sphere within a Square. One of the important contributions of the Coast and Geodetic Survey to this branch of geodetic work is Special Publication No. 68, Elements of Map Projection with Applications to Map and Chart Construction. A revised edition of this work was issued in 1928.

In 1929 the United States Geological Survey published Formulas and Tables for the Construction of Polyconic Projections, compiled by C. H. Birdseye as Bulletin 809. This publication gives the coordinates in inches for various scales of maps such as are produced in that bureau. Some 40 pages of introductory text serve to explain the computation of the tables and their use in the construction of maps.

In the construction of maps for airways the Lambert conformal projection is used by the Coast and Geodetic Survey. The chief work in this line done up to the present time has consisted in the construction of maps for certain aerial mail routes. The work on sectional maps for general flying is just beginning and will be carried on until the whole country is covered by maps of this kind.

The United States Bureau of Foreign and Domestic Commerce has had constructed an interrupted map of the world on the sinusoidal equal-area projection which that bureau finds of great use in statistical work. This type of projection is certainly to be preferred in all cases where the relative area of various sections of the map come into consideration. Another equal-area world map has been constructed by S. W. Boggs, of the State Department, that is found to be very useful in certain statistical work of that department. It is coming to be recognized more and more that in the construction of a given map a projection should be chosen that will be best suited to the purpose in view.

A wall map of the United States, scale 1 part in 2,500,000, on the Albers equal-area projection with two standard parallels, has been compiled by the United States Geological Survey and is practically ready for engraving. After completion this map will be the official wall map for this country and should soon supersede all other types of wall maps in use in the various governmental departments. The extent of the United States is such as to be well fitted for mapping on a conical projection with two standard parallels, and the equal-area property is of great value in some uses for which the map may be required. Since there are always two directions at every point that have true length scale, this kind of a map is about as satisfactory as any for scaling approximate distances between places.

Some of the large radio broadcasting stations have found special use for the azimuthal equidistant projection with the station placed at the center of the projection. Such a map gives at once the azimuth and distance of any other point from the broadcasting station. Of course a separate map has to be prepared for each station, and this requires a considerable amount of computation and compilation if an accurate map is to be produced.