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WORLD LONGITUDE DETERMINATIONS BY THE UNITED STATES COAST AND GEODETIC SURVEY IN 1926

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ABSTRACT

During the autumn of 1926, a world-wide program of longitude determinations by a number of countries was carried out under the direction of a mixed commission of the International Astronomical Union and the International Geodetic and Geophysical Union. The chairman of this commission is Gen. G. Ferrié, of France. The stations were divided into two groups, a fundamental polygon of three stations encircling the globe and a number of secondary stations connected to this polygon.

Four of the stations were in United States territory. The observations at two of these stations, one at Niu, about 7 miles southeast of Honolulu, and the other at Fort Wm. McKinley, about 6 miles southeast of Manila, were made by the Coast and Geodetic Survey.

Recently a French publication [1] was issued, giving the final differences for the fundamental polygon, Algiers, Zikawei, and San Diego. With these data available, it seemed advisable for this bureau to publish the results for its two stations and to give the final differences of longitude from two of the fundamental stations, Zikawei and San Diego. For the convenience of those who wish to make a detailed study of all the results of the world longitude program, the data are here published in practically the same form as in Lambert's book, mentioned above.

The final adjusted longitudes of Niu and Fort Wm. McKinley, based on the final published longitudes of Zikawei and San Diego, are as follows:

Longitude of Niu = $10^h\ 30^m\ 55^s.282$ west of Greenwich; longitude of Fort Wm. McKinley = $8^h\ 04^m\ 12^s.641$ east of Greenwich.

INCEPTION OF WORLD LONGITUDE NET

At the meeting in Rome, in 1922, of the International Astronomical Union and the International Geodetic and Geophysical Union, it was proposed by the Bureau of Longitudes, on the initiative of Gen. G. Ferrié, to establish a world-wide network of longitude stations with differences of longitude determined simultaneously at the various stations. It was proposed to make use of radio signals from a few powerful radio stations as the means for comparing the local times at the different stations, and it was planned to make the local time determinations with some standard high-grade instrumental equipment.

A mixed commission of the two international unions with General Ferrié as chairman, was appointed at the Rome meeting to perfect plans for this project. At the Madrid meeting of the International Geodetic and Geophysical Union, in 1924, and at the meeting in Cambridge, in 1925, of the International Astronomical Union, a definite plan for the work was finally agreed upon, and it was decided to make the observations in October and November of 1926. According to this plan the stations of the net were divided into two groups, a fundamental polygon of three stations, Algiers, San Diego, and Zikawei, encircling the globe, and in the second group a number of secondary stations connected to the fundamental stations.

[1] Lambert, Armand, la Participation Française a la Révision des Longitudes Mondiales, Toulouse, 1928.

The observations at two of the secondary stations were undertaken by the Coast and Geodetic Survey. In the preliminary list of stations prepared by the commission these two stations were designated as Honolulu and Manila, at both of which places there were old longitude stations determined by the cable and wire-telegraph method. At both places, however, it was necessary to locate the new stations at some distance away from the old stations, in order to secure satisfactory conditions for the reception of the radio signals. At Honolulu the new station is on the coast, about 7 miles southeast of the city, at a place called Niu. At Manila the new station is about 6 miles southeast of the city, on the Government reservation at Fort Wm. McKinley. Both of the new stations were connected with the old cable stations by determining the differences of longitude astronomically.

The work at Niu was under the direction of Lieut. E. J. Brown who was assisted by Lieut. W. H. Bainbridge, and at Fort Wm. McKinley it was under the direction of Lieut. R. J. Sipe who was assisted by Ensign F. G. Bryan and by J. I. Edwards, wireless operator. These men deserve a great deal of credit for the successful completion of the observations in spite of formidable difficulties and with instrumental equipment much less elaborate than at many of the other stations of the net, several of which were at astronomical observatories. The preliminary field computations were made by Lieutenants Brown, Bainbridge, and Sipe. In making the office computations, the writer was assisted by Associate Mathematician F. W. Darling and Assistant Mathematician J. A. Duerksen, who also helped in preparing the manuscript of this publication.

In 1927 this bureau issued, in mimeograph form, the preliminary results at stations Niu and Fort Wm. McKinley. Before the final results could be computed, it was necessary to know the final adopted differences for the three stations of the principal world polygon—Algiers, San Diego, and Zikawei. These differences are now available in published form in a French report by Armand Lambert.[2] It seemed advisable at this time, therefore, to compute and publish the final differences for the two stations determined by this bureau. The results are here given as nearly as possible in the same form as in Lambert's publication. There are two reasons for this: It seemed impossible to improve on the general arrangement adopted by Lambert, and it was felt that a study of the results for the complete network of stations could be made more conveniently if all the data were published according to a standard form.

In preliminary discussions in regard to making the final adjustments for the various secondary stations, it was thought that the stations should be combined in two comprehensive nets, one for the Pacific area and another for the rest of the world. Informal plans were made for the Coast and Geodetic Survey to have charge of the Pacific adjustment. After considerable study of the matter, and after the experience gained in making the adjustment of its own two stations, this bureau finds it advisable to recommend that each organization in the Pacific area which took part in the world longitude work make the adjustment of its own stations.

Apparently nothing is to be gained by connecting a secondary station to a large number of other secondary stations, although

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[2] See footnote 1 on p. 1.

the small number of signals received at Fort Wm. McKinley made it desirable to connect this station in the adjustment with Niu (which, of course, is a secondary station) as well as with the principal stations of San Diego and Zikawei. Ordinarily, however, a secondary station can be connected with main polygon stations only, and the results should be as accurate as if it were connected also with several secondary stations. It is also true that each organization that made observations for the world longitude net is in a much better position to interpret its own observations and assign the proper weights, etc., than is any central office which might undertake the work.

METHODS AND APPARATUS

At each station a Bamberg broken-telescope transit equipped with a hand-driven transit micrometer was used for making the time observations, and the common practice of this bureau of observing time stars only, instead of part time and part azimuth stars, was employed.[3] The radio equipment consisted primarily of the long-wave radio-recording device, described in Special Publication No. 109, which has been used so successfully by this bureau for several years for longitude and gravity determinations. A short-wave receiver, constructed in the field, was also used at each station, and although it proved quite satisfactory for receiving the signals, it did not give satisfactory results because of an unexpectedly large and variable lag which could not be correctly evaluated.

One of the serious problems which confronted this bureau when plans were being made for the work was how to provide accurate timepieces in order to compare the time derived from the astronomical observations with the time of the radio signals, which were received at various times of day and night, often at intervals of several hours from the mean epoch of the astronomical determinations. Chronometers were not accurate enough for the purpose, and no Riefler or other astronomical clocks were available. Even if astronomical clocks had been available, it would have been impracticable to construct constant-temperature vaults and make the elaborate preparations necessary for their installation at these two field stations.

The problem was solved by Doctor Bowie, who suggested the use of a gravity pendulum as a precision timepiece.[4] The quarter-meter, half-second pendulum used in the gravity apparatus of the Coast and Geodetic Survey is a free-swinging pendulum of the invariable type. It is swung in an air-tight receiver in a partial vacuum. If the temperature and pressure conditions are kept fairly uniform and corrections are applied for decrease in amplitude, the pendulum will maintain a very constant rate, and for intervals of a few hours it constitutes a timepiece which is probably as accurate as any timepiece in existence at the present time.

The method of using the pendulum to meet the special requirements of the longitude work was as follows: The period of the pendulum was first carefully determined at the station in the manner usually employed

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[3] A description of the Bamberg broken-telescope transit and a detailed explanation of its use for time determinations will be found in U. S. Coast and Geodetic Survey Special Publication No. 35. The older methods employed by this bureau for its longitude determinations are described in Special Publication No. 14. The radio method is explained in Special Publication No. 109.

[4] See William Bowie, Use of the Gravity Pendulum as a Timepiece, U. S. Coast and Geodetic Survey Serial No. 356, Washington, 1926.

at a field gravity station.[5] The pendulum was then used to check the rate of the chronometer over the interval between the mean epoch of the time observations and the time of the radio signal. The comparison between the chronometer and the swinging pendulum was made by the method of coincidences, as in gravity determinations.

The time could be carried over an interval of 12 hours in this manner with very little loss in accuracy. This was proved in several cases by comparing a given radio signal which happened to come

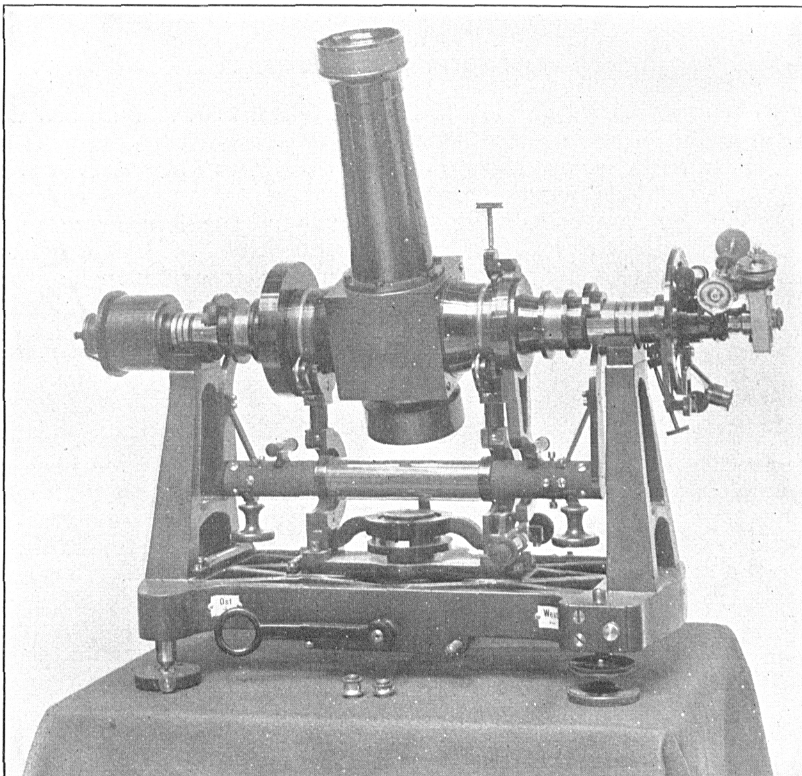

FIGURE 1.—BAMBERG BROKEN-TELESCOPE TRANSIT

This type of instrument was used for making the local time observations at both Niu and Fort Wm. McKinley.

about midway between the mean epochs of the time observations on succeeding nights with each of the two time determinations. The results of the two comparisons agreed within one or two hundredths of a second in most cases.

The pendulum was kept swinging almost continuously at Niu during the two months of longitude observations, and many of the radio signals, which could not have been used otherwise, were thus connected with the local time observations. At Fort Wm. McKinley the observer did not attempt to use the pendulum as a timepiece, as he was able to make star observations near the time of all signals that he was

[5] See Clarence H. Swick, Modern Methods for Determining the Intensity of Gravity, U. S. Coast and Geodetic Survey Special Publication No. 69, Washington, 1921.

able to receive. He did, however, make a determination of gravity at the station by swinging the pendulums for several days.

In the following tables it will be noticed that the number of determinations at Fort Wm. McKinley is rather small. This was due to

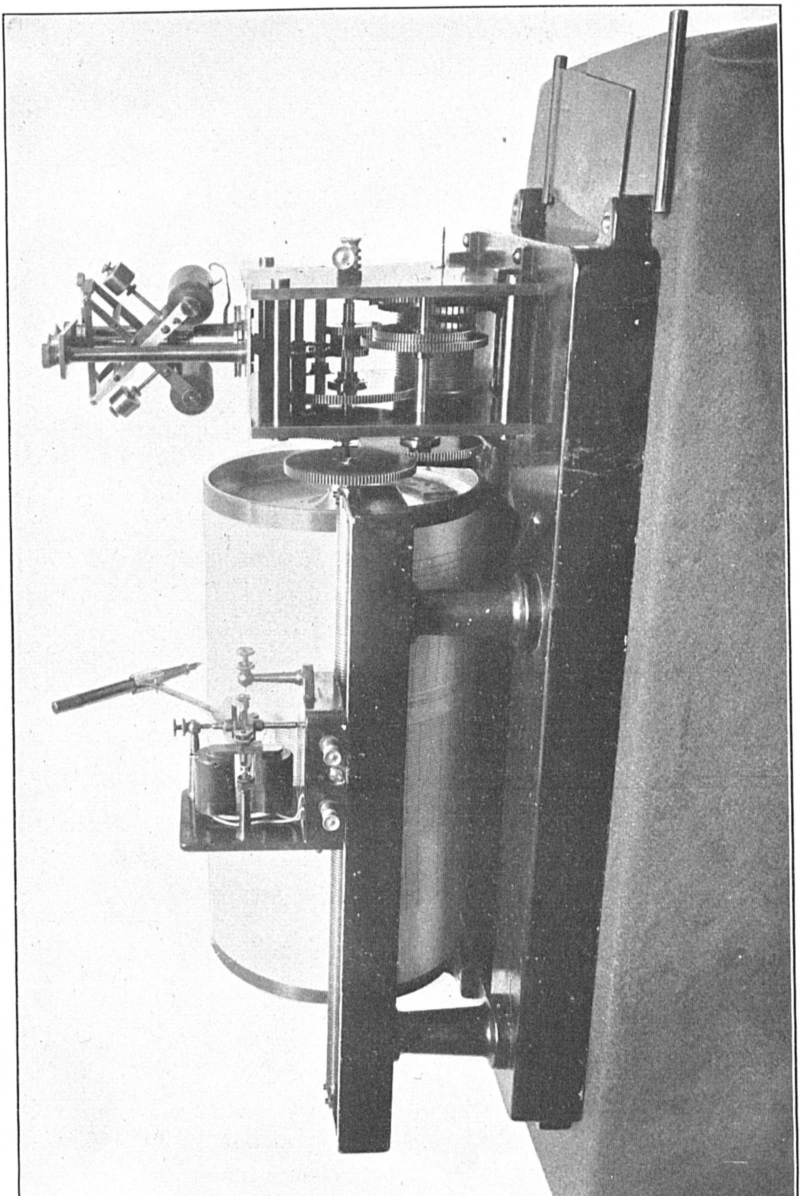

FIGURE 2.—CHRONOGRAPH

The radio time signals and the transit star observations were recorded on this type of chronograph at both stations.

several causes. The observer was unavoidably late in reaching his station and did not have time enough to get his instruments and apparatus in working order before the 1st of October, when the work was supposed to start. His chief difficulty was with the radio apparatus, for although this apparatus was in good condition when it left Washington, the long shipment and bad climatic conditions had ruined several of the parts by the time attempts were made to use it in the field. A great deal of rewiring had to be done, not only on

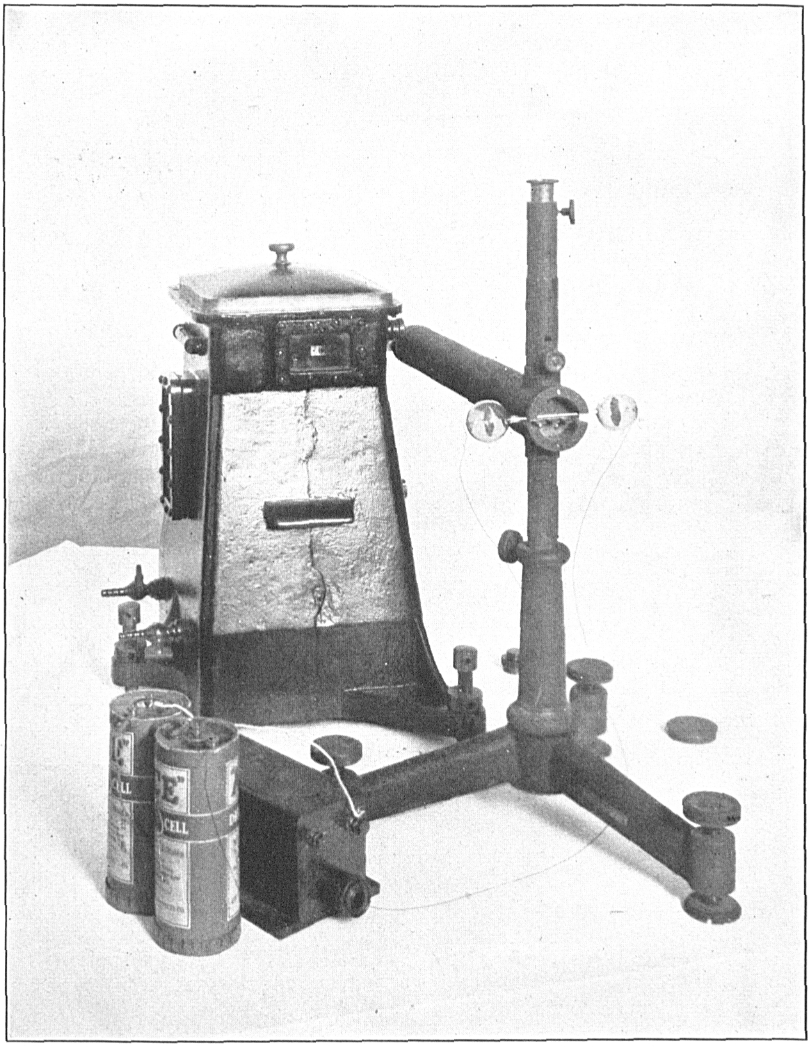

FIGURE 3.—GRAVITY RECEIVER AND INTERFEROMETER

The gravity pendulum was used in place of a precise clock at station Niu. As at an ordinary gravity station, the pendulum was swung under a partial vacuum in the receiver shown here. The interferometer was used to determine the slight sway of the receiver caused by the oscillations of the pendulum in order that a correction could be applied for the flexure.

the radio set but on the chronograph, longitude switchboard, and other parts of the instrumental equipment.

In his report on the work, Lieutenant Sipe makes grateful acknowledgment to various ones for the assistance he received in making repairs to his apparatus, in erecting his observatory, and in making other preparations for the work. He mentions especially Lieutenant

Paddock, who was in charge of the Santiago radio station, and Mr. Eason, a radio engineer at the Cavite Navy Yard.

For the work at Niu, Lieutenant Brown, in his report, mentions the valuable cooperation and assistance of Surveyor General Wall,

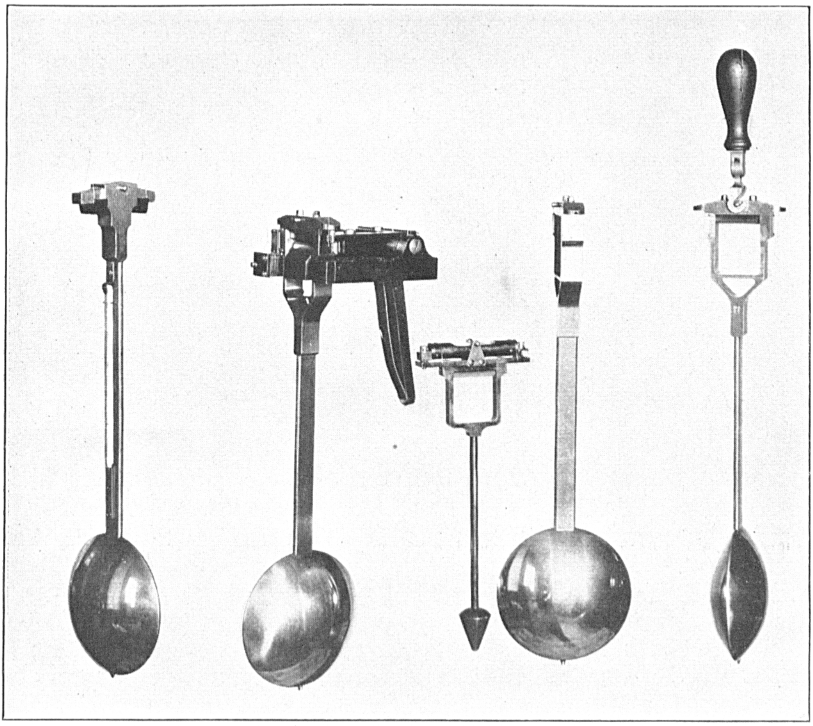

FIGURE 4.—GRAVITY PENDULUMS

The pendulum to the left is called the dummy. It carries the thermometer but is not permitted to swing. The pendulum in the center has a level mounted on it which is used to level the knife edge. The three others shown are the gravity pendulums. The one to the left of the center is supported on the knife edge.

Admiral McDonald and the radio division of the Navy, and the technical staff of the Radio Corporation of America.

SIGNALS

The following table contains a list of the signals received at Niu and Fort Wm. McKinley, showing the Greenwich civil times at which the signals were emitted, the wave lengths, and other data.

Signals received at Niu and Fort Wm. McKinley

Reference number of signal	Greenwich civil time of signal	Wave length of signal	Radio station emitting	Type of signal
		Meters		
3	3. 20- 3. 25	25	Bellevue	Rhythmic.
4	3. 20- 3. 25	75	do	Do.
5	3. 30- 3. 35	11, 500	Honolulu	Do.
6	3. 40- 3. 45	37	do	Do.
15	10. 20-10. 25	75	Bellevue	Do.
16	10. 30-10. 35	11, 500	Honolulu	Do.
17	10. 40-10. 45	37	do	Do.
19	11. 30-11. 35	15, 800	Saigon	Do.
23	19. 00-19. 05	15, 800	do	Do.
31	20. 30-20. 35	11, 500	Honolulu	Do.
32	20. 40-20. 45	37	do	Do.

The beat interval of all the above signals was about 60/61 mean time second. Saigon sent 300 beats for each signal and the rest of the stations 306 beats, although occasionally a few extra beats were sent at the end of the signal. Identification of the beats was assured in

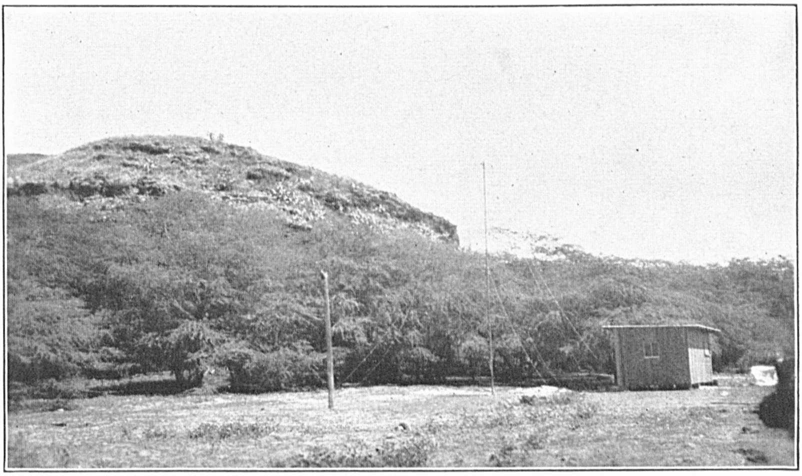

FIGURE 5.—OBSERVATORY AND ANTENNA AT NIU (NEAR HONOLULU)

The far end of the antenna was supported by a pole which stood on the rocky knob in the left background.

the following manner. The 60th, 120th, 180th, 240th, and 300th beats of the Honolulu signals were omitted; the 1st, 62d, 123d, 184th, 245th, and 306th beats of the Bellevue signals were elongated; the 60th, 120th, 180th, and 240th beats of the Saigon signals were elon-

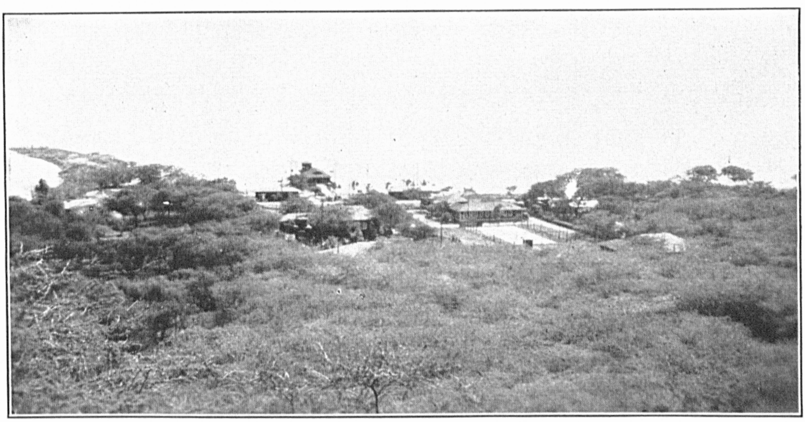

FIGURE 6.—U. S. NAVY RADIO STATION AT WAILUPE

The Honolulu signals were controlled from this station which is only about 2 miles from Niu.

gated. The Saigon signals were subject to a large and variable rate, and the factor for reducing each beat to the last or 300th beat was obtained from the internal evidence within the series of beats.

Although the sending clock at Honolulu had a very much smaller rate than the clock at Saigon, this rate was taken into account in computing the reduction factor used in reducing each beat read from the chronograph sheet to the final or 306th beat and in computing the first beat of each Honolulu signal from the derived time of the 306th.

The Bellevue signals were controlled by the Naval Observatory clock and so no rate correction was required.

Two of the following tables, one for Niu and one for Fort Wm. McKinley (see pp. 11–13 and 21), give the local sidereal times of the reception of both the first and last beats of each radio signal. The two beats are not independently determined. The time of the last beat of each signal was first derived and the time of the first beat was then computed from that. For the Bellevue signals the interval between the first and last beat was $300^{s}.821$. For the Honolulu signals the interval varied from $300^{s}.805$ to $300^{s}.809$ and for the Saigon signals it varied from $294^{s}.515$ to $294^{s}.688$. The interval for the Saigon signals may in some cases be in error by as much as several hundredths of a second as static interference made some of the Saigon chronograph sheets very difficult to read.

LAGS

The transit-circuit lag of Bamberg transit No. 20 and longitude switchboard No. 2, the radio receiver lags of the long-wave and short-wave sets used at Niu, and the personal equation of the Niu observer were determined in Washington. The total correction for lag amounted to $+0^{s}.030$ when the long-wave set was used, and $+0^{s}.023$ when the short-wave set was used. These corrections were applied to all observations at Niu and also to those at Fort Wm. McKinley.

In deriving preliminary longitude differences between Niu and Washington and between Niu and San Diego, by comparing the reception times of the various signals with the reception times at Washington and San Diego, it was discovered that there was a fairly consistent discrepancy of about $0^{s}.07$ between the results derived from the short-wave signals and those derived from the long-wave signals. This was undoubtedly due mostly to an uncorrected lag in the short-wave receiver at Niu. As the Naval Observatory observers were able to make very careful determinations of the lags of their short-wave receivers in the field, and as this bureau's observer was unable to do this, it was decided to attribute the entire discrepancy to a lag in the Niu short-wave receiver. All times for signals Nos. 3, 4, 6, 15, 17, and 32 at Niu have therefore been decreased by $0^{s}.07$. At Fort Wm. McKinley a comparison of the reception times with those at Niu, San Diego, and Washington seemed to show an uncorrected lag of $0^{s}.02$ in the short-wave receiver. All times for signal No. 17 at this station have therefore been decreased by this amount. It is recommended that other stations comparing their reception times with those of this bureau use only the long-wave signals unless this gives an inadequate number of comparisons. The data given in this publication for the short-wave signals should be used with caution. No short-wave signals were used in computing the longitudes of Niu and Fort Wm. McKinley.

TRANSMISSION TIMES

Corrections for the interval of time required for the signals to travel from the radio transmitting station to the receiving station were not applied in deriving the signal times listed in the two tables on pages 11–13 and 21. These tables therefore give the local sidereal times at the respective receiving stations for the instants at which the first and last beats of each radio signal were received at these stations. Transmission times were taken into account only in computing the differences of longitude between stations, as shown in the tables on pages 17 and 24. The computations of the transmission-time corrections are shown on pages 17 and 23. The velocity of propagation of radio

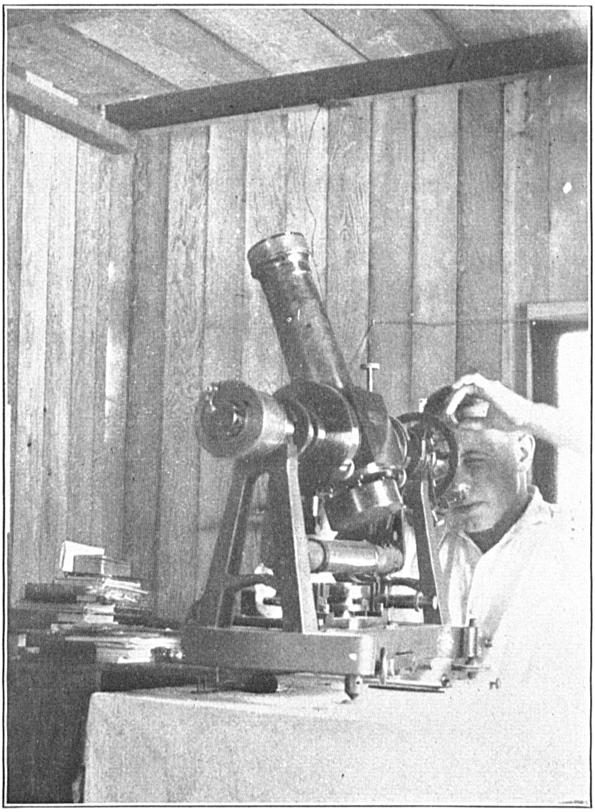

FIGURE 7.—MAKING STAR OBSERVATIONS AT NIU

The local sidereal time was determined on every clear night during the two months of the international program.

waves was assumed to be equal to the velocity of light, or approximately 300,000 kilometers per second.

RESULTS AT STATION NIU (near Honolulu)

DESCRIPTION OF STATION

Station Niu is about 7 miles southeast of Honolulu, Island of Oahu, Hawaii, at Niu, on the Chas. Lucas dairy ranch, 4 meters north of the stone wall on the north side of the road and about 100 meters west of the Lucas residence. The station is marked by a standard disk triangulation station mark of the U. S. Coast and Geodetic Survey set in concrete, stamped "Niu longitude 1926."

Local sidereal times of reception of radio signals

SIGNALS FROM BELLEVUE, NO. 3 (3.20-3.25; 25 METERS)[1]

Date, 1926	Local sidereal time: Beat No. 1	Local sidereal time: Beat No. 306
	h. m. s.	*h. m. s.*
Oct. 20	18 40 24.413	18 45 25.234

SIGNALS FROM BELLEVUE, NO. 4 (3.20-3.25; 75 METERS)[1]

Date, 1926	Beat No. 1	Beat No. 306
Nov. 24	20 58 23.905	21 03 24.726
Nov. 27	21 10 13.594	21 15 14.415
Nov. 28	14 10.157	19 10.978

SIGNALS FROM HONOLULU, NO. 5 (3.30-3.35; 11,500 METERS)

Date, 1926	Local sidereal time: Beat No. 1	Local sidereal time: Beat No. 306	Date, 1926	Local sidereal time: Beat No. 1	Local sidereal time: Beat No. 306
	h. m. s.	*h. m. s.*		*h. m. s.*	*h. m. s.*
Oct. 12	18 19 30.710	18 24 31.516	Nov. 5	19 54 32.062	19 59 32.870
Oct. 13	23 22.910	28 23.716	Nov. 7	20 01 18.815	20 06 19.624
Oct. 14	27 15.337	32 16.143			
Oct. 15	31 07.786	36 08.592	Nov. 9	10 03.570	15 04.379
Oct. 19	46 37.533	51 38.340	Nov. 10	13 56.305	18 57.114
			Nov. 11	17 49.231	22 50.040
Oct. 20	50 30.058	55 30.865	Nov. 15	32 21.247	37 22.056
Oct. 22	59 14.440	19 04 15.247	Nov. 18	44 59.801	50 00.610
Oct. 26	19 14 44.550	19 45.357			
Oct. 27	20 35.515	25 36.322	Nov. 19	48 52.938	53 53.747
Oct. 29	26 22.621	31 23.429	Nov. 24	21 09 18.563	21 14 19.372
Oct. 30	30 15.600	35 16.408	Nov. 25	12 12.555	17 13.364
			Nov. 27	20 57.809	25 58.618
Nov. 2	19 41 53.945	19 46 54.753	Nov. 28	24 51.047	29 51.856
Nov. 3	45 46.805	50 47.613	Nov. 30	32 36.979	37 37.788
Nov. 4	49 39.785	54 40.593			
			Dec. 1	21 36 29.973	21 41 30.782

SIGNALS FROM HONOLULU, NO. 6 (3.40-3.45; 37 METERS)[1]

Date, 1926	Beat No. 1	Beat No. 306	Date, 1926	Beat No. 1	Beat No. 306
Oct. 19	18 57 28.456	19 02 29.263	Nov. 10	20 23 48.126	20 28 48.935
Oct. 26	19 24 36.343	29 37.150	Nov. 11	27 41.043	32 41.852
Oct. 27	28 28.957	33 29.764	Nov. 15	42 13.066	47 13.875
Oct. 29	36 14.393	41 15.201	Nov. 19	58 44.729	21 03 45.538
Oct. 30	40 07.403	45 08.211	Nov. 24	21 17 12.033	22 12.842
Nov. 2	19 51 45.721	19 56 46.529	Nov. 25	22 04.378	27 05.187
Nov. 3	55 38.605	20 00 39.413	Nov. 27	30 49.616	35 50.425
Nov. 4	20 00 30.703	05 31.511	Nov. 28	34 42.851	39 43.660
Nov. 5	04 23.803	09 24.611	Nov. 30	42 28.773	47 29.582
Nov. 7	12 09.729	17 10.538			
			Dec. 1	21 46 21.788	21 51 22.597

SIGNALS FROM BELLEVUE, NO. 15 (10.20-10.25; 75 METERS)[1]

Date, 1926	Beat No. 1	Beat No. 306	Date, 1926	Beat No. 1	Beat No. 306
Nov. 9	3 00 24.591	3 05 25.412	Nov. 23	3 55 36.390	4 00 37.211
Nov. 10	04 21.159	09 21.980	Nov. 25	4 03 29.484	08 30.305
Nov. 11	08 17.697	13 18.518	Nov. 27	11 22.555	16 23.376
Nov. 13	16 10.763	21 11.584	Nov. 30	23 12.338	28 13.159
Nov. 19	39 50.156	44 50.977			

[1] These short-wave signals were not used in computing the longitude of Niu. See p. 9.

Local sidereal times of reception of radio signals—Continued

SIGNALS FROM HONOLULU, NO. 16 (10.30-10.35; 11,500 METERS)

Date, 1926	Local sidereal time		Date, 1926	Local sidereal time	
	Beat No. 1	Beat No. 306		Beat No. 1	Beat No. 306
	h. m. s.	*h. m. s.*		*h. m. s.*	*h. m. s.*
Oct. 8	1 04 10.138	1 09 10.943	Nov. 8	3 07 18.762	3 12 19.571
Oct. 11	15 47.092	20 47.898	Nov. 9	10 12.230	15 13.039
Oct. 12	20 38.475	25 39.281	Nov. 10	15 04.286	20 05.095
Oct. 14	28 23.192	33 23.998	Nov. 11	18 57.180	23 57.989
Oct. 15	32 15.534	37 16.340	Nov. 13	25 43.538	30 44.347
Oct. 19	47 45.350	52 46.157	Nov. 15	34 28.483	39 29.292
Oct. 20	51 37.896	56 38.703	Nov. 18	46 07.866	51 08.675
Oct. 26	2 15 52.422	2 20 53.229	Nov. 19	50 00.973	55 01.782
Oct. 27	19 45.016	24 45.823	Nov. 23	4 05 34.123	4 10 34.932
Oct. 29	27 30.584	32 31.392	Nov. 24	10 26.629	15 27.438
Oct. 30	31 23.544	36 24.352	Nov. 25	13 20.563	18 21.372
Nov. 2	2 43 01.899	2 48 02.707	Nov. 27	21 06.658	26 07.467
Nov. 3	46 54.766	51 55.574	Nov. 28	25 58.972	30 59.781
Nov. 4	50 47.785	55 48.593	Nov. 29	29 51.983	34 52.792
Nov. 5	54 40.898	59 41.706	Nov. 30	33 44.971	38 45.780
Nov. 7	3 03 25.949	3 08 26.758			

SIGNALS FROM HONOLULU, NO. 17 (10.40-10.45; 37 METERS)[1]

Oct. 20	2 01 29.688	2 06 30.495	Nov. 15	3 44 20.287	3 49 21.096
Oct. 26	25 44.189	30 44.996	Nov. 18	55 59.673	4 01 00.482
Oct. 29	37 22.362	42 23.170	Nov. 19	59 52.762	04 53.571
Oct. 30	41 15.312	46 16.120	Nov. 24	4 20 18.406	25 19.215
Nov. 2	2 52 53.688	2 57 54.496	Nov. 25	23 12.377	28 13.186
Nov. 5	3 04 32.636	3 09 33.444	Nov. 27	30 58.436	35 59.245
Nov. 8	17 10.505	22 11.314	Nov. 28	35 50.757	40 51.566
Nov. 9	21 03.203	26 04.012	Nov. 29	39 43.791	44 44.600
Nov. 11	28 48.984	33 49.793	Nov. 30	43 36.789	48 37.598
Nov. 13	36 34.498	41 35.307			

SIGNALS FROM SAIGON, NO. 19 (11.30-11.35; 15,800 METERS)

Date, 1926	Local sidereal time		Date, 1926	Local sidereal time	
	Beat No. 1	Beat No. 300		Beat No. 1	Beat No. 300
	h. m. s.	*h. m. s.*		*h. m. s.*	*h. m. s.*
Oct. 30	3 29 18.715	3 34 13.344	Nov. 15	4 34 06.942	4 39 01.630
Nov. 3	3 44 05.706	3 49 00.329	Nov. 18	44 46.436	49 41.026
Nov. 8	4 02 25.673	4 07 20.203	Nov. 23	5 04 15.745	5 09 10.353
Nov. 9	08 03.557	12 58.123	Nov. 25	12 41.214	17 35.798
Nov. 13	22 46.112	27 40.657			

SIGNALS FROM SAIGON, NO. 23 (19.00-19.05; 15,800 METERS)

Nov. 18	12 16 02.955	12 20 57.572	Nov. 23	12 34 46.143	12 39 40.670
Nov. 19	20 06.086	25 00.709			

[1] These short-wave signals were not used in computing the longitude of Niu. See p. 9.

Local sidereal times of reception of radio signals—Continued

SIGNALS FROM HONOLULU, NO. 31 (20.30–20.35; 11,500 METERS)

Date, 1926	Local sidereal time					
	Beat No. 1			Beat No. 306		
	h.	*m.*	*s.*	*h.*	*m.*	*s.*
Oct. 11	11	18	23.038	11	23	23.844
Oct. 12		22	15.265		27	16.071
Oct. 13		26	07.646		31	08.452
Oct. 14		30	00.041		35	00.847
Oct. 15		33	52.368		38	53.174
Oct. 18		45	29.791		50	30.598
Oct. 19		49	22.218		54	23.025
Oct. 20		53	14.838		58	15.645
Oct. 21		57	07.449	12	02	08.256
Oct. 22	12	01	00.184		06	00.991
Oct. 25		13	36.805		18	37.612
Oct. 26		17	29.326		22	30.133
Oct. 27		21	21.918		26	22.725
Oct. 28		25	14.704		30	15.511
Oct. 29		29	07.682		34	08.490
Nov. 1	12	40	46.097	12	45	46.905
Nov. 2		44	38.904		49	39.712
Nov. 3		48	31.847		53	32.655
Nov. 4		52	24.856		57	25.664
Nov. 6	13	01	10.162	13	06	10.970

Date, 1926	Local sidereal time					
	Beat No. 1			Beat No. 306		
	h.	*m.*	*s.*	*h.*	*m.*	*s.*
Nov. 7	13	05	03.072	13	10	03.881
Nov. 8		08	55.704		13	56.513
Nov. 9		12	48.492		17	49.301
Nov. 10		16	41.435		21	42.244
Nov. 11		20	34.180		25	34.989
Nov. 12		24	26.946		29	27.755
Nov. 13		28	19.737		33	20.546
Nov. 14		32	12.446		37	13.255
Nov. 15		36	05.687		41	06.496
Nov. 17		43	51.875		48	52.684
Nov. 23	14	08	10.601	14	13	11.410
Nov. 24		12	03.790		17	04.599
Nov. 25		15	56.820		20	57.629
Nov. 26		19	49.812		24	50.621
Nov. 27		23	42.846		28	43.655
Nov. 28		27	36.049		32	36.858
Nov. 29		31	29.031		36	29.840
Nov. 30		35	22.018		40	22.827

SIGNALS FROM HONOLULU, NO. 32 (20.40–20.45; 37 METERS)[1]

Date, 1926	Local sidereal time					
	Beat No. 1			Beat No. 306		
	h.	*m.*	*s.*	*h.*	*m.*	*s.*
Oct. 15	11	43	44.110	11	48	44.916
Oct. 18		55	21.532	12	00	22.339
Oct. 19		59	13.931		04	14.738
Oct. 20	12	03	06.637		08	07.444
Oct. 21		06	59.250		12	00.057
Oct. 22		11	51.147		16	51.954
Oct. 25		23	28.506		28	29.313
Oct. 28		35	06.471		40	07.278
Oct. 29		38	59.466		44	00.274
Nov. 1	12	50	37.900	12	55	38.708
Nov. 3		58	23.583	13	03	24.391
Nov. 4	13	02	16.605		07	17.413
Nov. 6		11	01.903		16	02.711
Nov. 7		14	54.788		19	55.597
Nov. 8		18	47.464		23	48.273

Date, 1926	Local sidereal time					
	Beat No. 1			Beat No. 306		
	h.	*m.*	*s.*	*h.*	*m.*	*s.*
Nov. 9	13	22	40.299	13	27	41.108
Nov. 11		30	25.995		35	26.804
Nov. 12		35	18.774		40	19.583
Nov. 13		38	11.552		43	12.361
Nov. 14		42	04.245		47	05.054
Nov. 15		45	57.490		50	58.299
Nov. 17		53	43.660		58	44.469
Nov. 19	14	01	29.973	14	06	30.782
Nov. 23		18	02.411		23	03.220
Nov. 24		21	55.587		26	56.396
Nov. 25		25	48.628		30	49.437
Nov. 26		29	41.604		34	42.413
Nov. 27		33	34.671		38	35.480
Nov. 28		37	27.873		42	28.682
Nov. 29		41	20.837		46	21.646
Nov. 30		45	13.825		50	14.634

[1] These short-wave signals were not used in computing the longitude of Niu. See p. 9.

COMPUTATION OF LONGITUDE, STATION NIU

The following tables and the least-squares adjustment on pages 17 and 18 show how the longitude of Niu was obtained. The first table gives the local sidereal times at which Honolulu signal No. 16 was received by Niu and Zikawei on the different days on which that signal was received by both stations. The differences of these local times, shown in the last column of the table, are preliminary, uncorrected values of the difference in longitude between the two stations, Niu and Zikawei. The mean of these differences is given a weight equal to the number of accepted values used in obtaining it. The criterion for making rejections of outstanding differences is explained in the footnote on page 14.

Following this table are similar tables for the other signals received by both Niu and Zikawei and also for the signals received by both Niu and San Diego.

The next table shows the computation of the corrections for transmission times. These corrections are applied in the next following table to the mean differences of longitude as derived from the various sets of signals. Weighted means are then taken to give the corrected differences of longitude between Niu and each of the two fundamental stations, Zikawei and San Diego.

The final step in the computation is the least-squares adjustment to obtain corrections to the two differences of longitude to make them sum up to the fixed difference between San Diego and Zikawei. This adjustment is very simple and requires no explanation. It is given in complete detail on pages 17 and 18.

Comparison of local sidereal times at Niu and Zikawei

HONOLULU SIGNALS NO. 16

Date, 1926	Sidereal time of 306th beat		Difference, Niu minus Zikawei
	Niu	Zikawei [1]	
	h. m. s.	*h. m. s.*	*h. m. s.*
Oct. 8	1 09 10.943	19 45 49.11	5 23 21.833
Oct. 12	1 25 39.281	20 02 30.36	08.921 R [2]
Oct. 14	1 33 23.998	20 10 02.12	21.878 R [2]
Oct. 19	1 52 46.157	20 29 24.37	21.787
Oct. 20	1 56 38.703	20 33 16.15	22.553 R [2]
Oct. 26	2 20 53.229	20 57 31.48	21.749
Oct. 27	2 24 45.823	21 01 24.03	21.793
Oct. 29	2 32 31.392	21 09 09.57	21.822
Oct. 30	2 36 24.352	21 13 02.53	21.822
Nov. 2	2 48 02.707	21 24 40.92	5 23 21.787
Nov. 3	2 51 55.574	21 28 33.78	21.794
Nov. 4	2 55 48.593	21 32 26.85	21.743
Nov. 7	3 08 26.758	21 45 04.99	21.768
Nov. 8	3 12 19.571	21 48 57.83	21.741
Nov. 10	3 20 05.095	21 56 43.27	21.825
Nov. 11	3 23 57.989	22 00 36.21	21.779
Nov. 15	3 39 29.292	22 16 07.49	21.802
Nov. 19	3 55 01.782	22 31 39.96	21.822
Nov. 24	4 15 27.438	22 52 05.65	21.788
Nov. 25	4 18 21.372	22 54 59.56	21.812
Nov. 30	4 38 45.780	23 15 24.09	21.690 R [2]
Mean [3]			5 23 21.792

[1] The times of the signals received at Zikawei as published in the report by Lambert (see footnote on p. 1) are given to only two decimal places of seconds. In this computation we have carried the differences between Niu and Zikawei to three decimal places in order to make this table consistent with those following. Although the third decimal place may seem to indicate a fictitious accuracy, it was deemed desirable to carry this decimal place in the computations.

The published times of the Zikawei signals appear to be in error in the minutes in a few instances and they have been arbitrarily changed in this table. Most of these changes have been verified by comparison with the San Diego records of the same signals.

[2] Rejections were made somewhat arbitrarily according to a rule which has been used by the Coast and Geodetic Survey for a number of years in its longitude computations. (See Coast and Geodetic Survey Special Pub. No. 14, fifth edition, p. 80.) Individual values which differed so much from the normal values as to be obviously in error were first rejected. A preliminary mean was then taken and additional rejections were made of values which differed 0ˢ.07 or more from this mean. After the final mean was taken some of the rejected values might be found to differ from it less than 0ˢ.07, but nevertheless they were allowed to remain as rejected values. It was found that this rule gave about the same rejections as the rule sometimes used by this bureau of rejecting values which differ from the mean by more than 3½ times the probable error of a single value.

[3] Weight of this mean equals 17.

Comparison of local sidereal times at Niu and Zikawei—Continued

SAIGON SIGNALS NO. 19

Date, 1926	Sidereal time of 300th beat		Difference, Niu minus Zikawei
	Niu	Zikawei [1]	
	h. m. s.	*h. m. s.*	*h. m. s.*
Oct. 30	3 34 13.344	22 10 51.49	5 23 21.854
Nov. 3	3 49 00.329	22 25 38.48	21.849
Nov. 8	4 07 20.203	22 44 58.43	21.773
Nov. 9	4 12 58.123	22 49 36.28	21.843
Nov. 13	4 27 40.657	23 04 18.83	21.827
Nov. 18	4 49 41.026	23 26 19.16	21.866
Nov. 23	5 09 10.353	23 45 48.55	21.803
Nov. 25	5 17 35.798	23 54 13.97	21.828
Mean [4]			5 23 21.830

[1] See footnote 1 on p. 14. [4] Weight of this mean equals 8.

Comparison of local sidereal times at Niu and San Diego

HONOLULU SIGNALS NO. 16

Date, 1926	Sidereal time of 306th beat		Difference, San Diego minus Niu
	Niu	San Diego	
	h. m. s.	*h. m. s.*	*h. m. s.*
Oct. 8	1 09 10.943	3 51 17.833	2 42 06.890
Oct. 11	1 20 47.898	4 02 54.777	06.879
Oct. 12	1 25 39.281	4 07 46.181	06.900
Oct. 14	1 33 23.998	4 15 30.896	06.898
Oct. 15	1 37 16.340	4 19 23.243	06.903
Oct. 19	1 52 46.157	4 34 53.133	06.976
Oct. 20	1 56 38.703	4 38 45.637	06.934
Oct. 26	2 20 53.229	5 03 00.130	06.901
Oct. 27	2 24 45.823	5 06 52.736	06.913
Oct. 29	2 32 31.392	5 14 38.311	06.919
Oct. 30	2 36 24.352	5 18 31.254	06.902
Nov. 2	2 48 02.707	5 30 09.638	2 42 06.931
Nov. 3	2 51 55.574	5 34 02.498	06.924
Nov. 4	2 55 48.593	5 37 55.537	06.944
Nov. 5	2 59 41.706	5 41 48.640	06.934
Nov. 7	3 08 26.758	5 50 33.707	06.949
Nov. 8	3 12 19.571	5 54 26.599	07.028 R [1]
Nov. 9	3 15 13.039	5 57 19.994	06.955
Nov. 10	3 20 05.095	6 02 12.001	06.906
Nov. 11	3 23 57.989	6 06 04.894	06.905
Nov. 13	3 30 44.347	6 12 51.258	06.911
Nov. 15	3 39 29.292	6 21 36.167	06.875
Nov. 18	3 51 08.675	6 33 15.580	06.905
Nov. 19	3 55 01.782	6 37 08.669	06.887
Nov. 23	4 10 34.932	6 52 41.861	06.929
Nov. 24	4 15 27.438	6 57 34.343	06.905
Nov. 25	4 18 21.372	7 00 28.247	06.875
Nov. 27	4 26 07.467	7 08 14.360	06.893
Nov. 28	4 30 59.781	7 13 06.672	06.891
Nov. 29	4 34 52.792	7 16 59.703	06.911
Nov. 30	4 38 45.780	7 20 52.678	06.898
Mean [2]			2 42 06.911

[1] See footnote 2 on p. 14. [2] Weight of this mean equals 30.

Comparison of local sidereal times at Niu and San Diego—Continued

SAIGON SIGNALS NO. 19

Date, 1926	Sidereal time of 300th beat		Difference, San Diego minus Niu
	Niu	San Diego	
	h. m. s.	*h. m. s.*	*h. m. s.*
Oct. 30	3 34 13.344	6 16 20.241	2 42 06.897
Nov. 3	3 49 00.329	6 31 07.255	06.926
Nov. 8	4 07 20.203	6 49 27.234	07.031 R [1]
Nov. 9	4 12 58.123	6 55 05.077	06.954
Nov. 13	4 27 40.657	7 09 47.617	06.960
Nov. 15	4 39 01.630	7 21 08.523	06.893
Nov. 18	4 49 41.026	7 31 47.941	06.915
Nov. 23	5 09 10.353	7 51 17.300	06.947
Nov. 25	5 17 35.798	7 59 42.713	06.915
Mean [3]			2 42 06.926

[3] Weight of this mean equals 8.

HONOLULU SIGNALS NO. 31

Date, 1926	Sidereal time of 306th beat		Difference, San Diego minus Niu
	Niu	San Diego	
	h. m. s.	*h. m. s.*	*h. m. s.*
Oct. 11	11 23 23.844	14 05 30.742	2 42 06.898
Oct. 12	11 27 16.071	14 09 22.929	06.858
Oct. 13	11 31 08.452	14 13 15.278	06.826 R [1]
Oct. 14	11 35 00.847	14 17 07.761	06.914
Oct. 15	11 38 53.174	14 21 00.094	06.920
Oct. 18	11 50 30.598	14 32 37.513	06.915
Oct. 19	11 54 23.025	14 36 29.963	06.938
Oct. 20	11 58 15.645	14 40 22.570	06.925
Oct. 21	12 02 08.256	14 44 15.175	06.919
Oct. 22	12 06 00.991	14 48 07.907	06.916
Oct. 25	12 18 37.612	15 00 44.511	06.899
Oct. 26	12 22 30.133	15 04 37.064	06.931
Oct. 27	12 26 22.725	15 08 29.661	06.936
Oct. 28	12 30 15.511	15 12 22.411	06.900
Oct. 29	12 34 08.490	15 16 15.398	06.908
Nov. 1	12 45 46.905	15 27 53.820	2 42 06.915
Nov. 2	12 49 39.712	15 31 46.657	06.945
Nov. 3	12 53 32.655	15 35 39.634	06.979
Nov. 4	12 57 25.664	15 39 32.648	06.984 R [1]
Nov. 6	13 06 10.970	15 48 17.868	06.898
Nov. 7	13 10 03.881	15 52 10.809	06.928
Nov. 8	13 13 56.513	15 56 03.479	06.966
Nov. 9	13 17 49.301	15 59 56.202	06.901
Nov. 10	13 21 42.244	16 03 49.049	06.805 R [1]
Nov. 11	13 25 34.989	16 07 41.860	06.871
Nov. 12	13 29 27.755	16 11 34.699	06.944
Nov. 13	13 33 20.546	16 15 27.364	06.818 R [1]
Nov. 14	13 37 13.255	16 19 20.229	06.974
Nov. 15	13 41 06.496	16 23 13.291	06.795 R [1]
Nov. 17	13 48 52.684	16 30 59.613	06.929
Nov. 24	14 17 04.599	16 59 11.496	06.897
Nov. 25	14 20 57.629	17 03 04.537	06.908
Nov. 26	14 24 50.621	17 06 57.542	06.921
Nov. 27	14 28 43.655	17 10 50.750	07.095 R [1]
Nov. 28	14 32 36.858	17 14 43.758	06.900
Nov. 29	14 36 29.840	17 18 36.743	06.903
Nov. 30	14 40 22.827	17 22 29.801	06.974
Mean [4]			2 42 06.920

[1] See footnote 2 on p. 14.

[4] Weight of this mean equals 31.

Computation of transmission times

[See p. 10]

Longitude station	Radio transmitting station	Distance	Difference in distance	Correction for transmission time
		km.	*km.*	*s.*
Niu	Honolulu	12		
Zikawei	do	7, 950	−7, 938	+0. 026
Niu	Saigon	10, 140		
Zikawei	do	2, 110	+8, 030	−0. 027
San Diego	Honolulu	4, 222		
Niu	do	12	+4, 210	−0. 014
San Diego	Saigon	13, 319		
Niu	do	10, 140	+3, 179	−0. 011

Differences of longitude

NIU TO ZIKAWEI

Radio signal	Computed difference of longitude	Weight	Correction for transmission time	Corrected difference of longitude
	h. m. s.		*s.*	*h. m. s.*
Honolulu, No. 16	5 23 21. 792	17	+0. 026	5 23 21. 818
Saigon, No. 19	21. 830	8	−. 027	21. 803
Weighted mean				5 23 21. 813
Probable error				±. 005

SAN DIEGO TO NIU

Radio signal	Computed difference of longitude	Weight	Correction for transmission time	Corrected difference of longitude
	h. m. s.		*s.*	*h. m. s.*
Honolulu, No. 16	2 42 06. 911	30	−0. 014	2 42 06. 897
Saigon, No. 19	06. 926	8	−. 011	06. 915
Honolulu, No. 31	06. 920	31	−. 014	06. 906
Weighted mean				2 42 06. 903
Probable error				±. 003

Least-squares adjustment

[Fixed difference of longitude San Diego to Zikawei (main polygon)=8^h 05^m $28^s.733$]

Stations	Observed difference of longitude	Correction symbol	Weight	Least-squares correction	Adjusted difference of longitude
	h. m. s.			*s.*	*h. m. s.*
San Diego–Niu	2 42 06. 903	v_1	69	+0. 005	2 42 06. 908
Niu–Zikawei	5 23 21. 813	v_2	25	+. 012	5 23 21. 825
San Diego–Zikawei	8 05 28. 716				8 05 28. 733

Fixed difference, San Diego to Zikawei, minus observed difference equals $+0^s.017$.
Therefore,

$$v_1 + v_2 - 0.017 = 0$$

or

$$v_1 = 0.017 - v_2$$

Taking the weights into consideration, the quantity to be made a minimum is

$$69v_1^2 + 25v_2^2$$

Substituting the value of v_1 above, this reduces to

$$69\ (0.017 - v_2)^2 + 25v_2^2$$

Differentiating and equating to zero we obtain

$$138v_2 - 2.346 + 50v_2 = 0$$

$$v_2 = +0.012$$

$$v_1 = +0.005$$

FINAL LONGITUDE

A recent publication of the International Longitude Commission [6] gives the longitudes of 40 stations which were determined in the world longitude operations of 1926. As given there the longitude of San Diego is $7^h\ 48^m\ 48^s.374$ west of Greenwich, and of Zikawei is $8^h\ 05^m\ 42^s.893$ east. Applying the adjusted differences given above, we obtain the following result for Niu: **Longitude of Niu = $10^h\ 30^m\ 55^s.282$ west of Greenwich.**

The published value of Niu given in the report just mentioned is $10^h\ 30^m\ 55^s.279$ west. The difference, $0^s.003$, between the two values is probably due to somewhat different methods for making rejections in the computations. (See footnote 2, p. 14.)

ASTRONOMICAL CONNECTION OF NIU AND OLD CABLE STATION AT HONOLULU

Soon after the completion of the world longitude observations at Niu, an astronomical connection by the wire-telegraph method was made between this station and the old cable longitude station at Honolulu which was determined in 1903. Lieutenant Brown made the observations at Niu and Lieutenant Bainbridge at Honolulu. A straight-telescope transit was obtained from the Washington office for use at the former station.

Longitude differences were determined on four different nights. Unfortunately, the results are quite discordant as can be seen by the following table. As the general instructions of this bureau for longitude work do not require a field computation before leaving a station, provided four or more independent determinations are made, the lack of agreement between the different values was not discovered in time to permit additional determinations except at very great inconvenience and expense.

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[6] La Revision des Longitudes Mondiales, Commission internationale des Longitudes, par. T. S. F., Paris, 1929.

The range of values for this difference of longitude is probably greater than for any other difference determined by this bureau since the telegraphic method came into use. The trouble may have been caused by lateral refraction at the Honolulu station or by a defect of the straight-telescope instrument, which had not been used for a

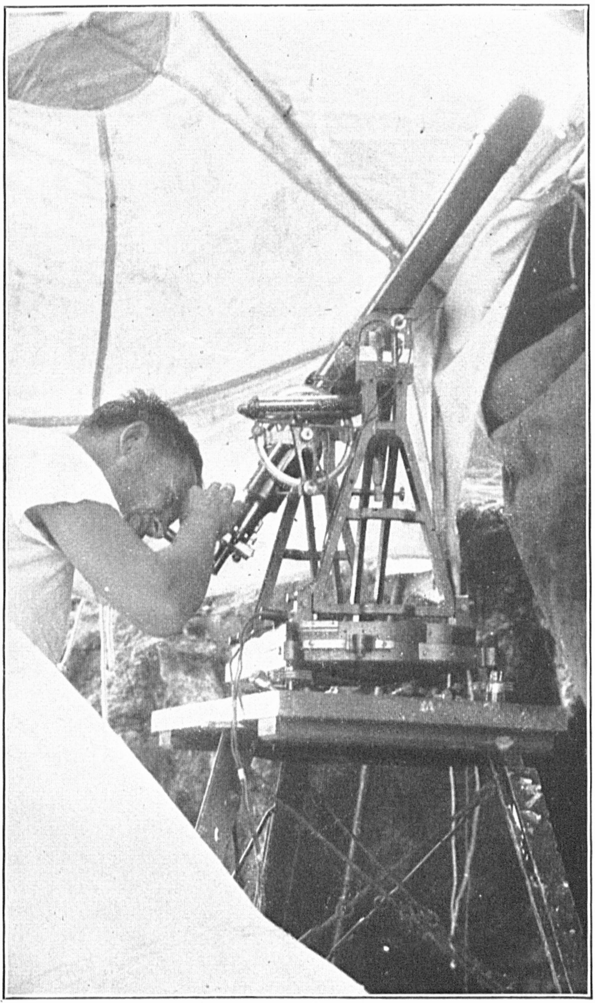

FIGURE 8.—MERIDIAN TELESCOPE

This is an old type of portable astronomical transit. It was used for the radio determination of the old cable longitude station at Honolulu.

number of years. Whatever may have been the reason for the large discrepancies, there is no way of telling definitely what values are most nearly correct, and it was decided to reject all of them, although the first two are in fairly close agreement. A new series of determinations between these two stations will be made some time in the future if it can be done without too great expense.

Difference of longitude, Niu to Honolulu

Date	Longitude difference	Date	Longitude difference
1927	*s.*	1927	*s.*
Jan. 31	32.400	Feb. 3	32.522
Feb. 1	32.337	Feb. 4	32.624

Reduction of new pier to old pier = +0^{s}015

The cable determination in 1903 gave the longitude of Honolulu as 10^{h} 31^{m} 27^{s}732 west.[7] This value is based on 5^{h} 08^{m} 15^{s}784 west as the adjusted longitude of Washington. However, the 1926 radio determinations, in which Niu is included, gives the longitude of Washington as 5^{h} 08^{m} 15^{s}751 west.[8] If we apply a correction for this change in the Washington longitude, we obtain for the old Honolulu determination a value of 10^{h} 31^{m} 27^{s}699 west.

The longitude obtained for Niu (see p. 18) is 10^{h} 30^{m} 55^{s}282 west, and therefore the difference between the two stations, as derived in this manner, is 32^{s}417. This agrees closely with the first one only of the four determinations given above, which, after correction for the distance between the old and new piers, is 32^{s}415.

DESCRIPTION OF OLD CABLE LONGITUDE STATION AT HONOLULU

The original description of 1903 of the Honolulu cable longitude station reads as follows:[9]

In the grounds of the United States naval station, 88.97 meters north and 505.97 meters east of Harbor Light. The station is marked by a concrete pier 14 by 26 inches in cross section, and 3 feet high, resting on a concrete foundation, 3 by 4 feet in cross section, which in turn rests upon coral rock 2½ feet below the surface of the ground. North of the center of the pier, and 3.435 meters therefrom, is a galvanized-iron pipe 2½ feet long set in cement, with its center marked by a copper bolt. This is a point of the Territorial survey.

When the station was visited in 1926, it was found that the marks had been destroyed by building operations of the United States Navy. The approximate position of the old pier was reestablished by means of data furnished by the surveyor general of Hawaii. The station as relocated in 1926 is on the east side of the main building in the naval station grounds. It is 2½ feet south of the cement walk leading to the north porch steps and 1 foot east of the board walk which is close to the building and parallel to it. The point was remarked with an iron pin driven 2 inches below the surface of the ground.

RADIO DETERMINATION IN 1928 OF OLD CABLE LONGITUDE STATION AT HONOLULU

Because of the discordant results obtained in 1927 in connecting Niu with the old cable station at Honolulu, it was decided in the spring of 1928 to make a radio determination of the Honolulu station. This could be done at small expense, since Lieutenant Brown was already at Honolulu making preparations for astronomical work on the outlying reefs and small islands which extend northwest from the main islands of the Hawaiian group. A meridian telescope, a short-wave

[7] See Coast and Geodetic Survey Special Publication No. 110, p. 40.
[8] See publication mentioned in footnote on p. 18.
[9] See Coast and Geodetic Survey Special Publication No. 110, p. 278.

radio receiver, and the necessary auxiliary apparatus were on hand for the work. A telegraphic determination between Niu and Honolulu to check the 1927 determination could not be made because only one set of instruments was available.

Observations were made on April 19 and 20, 1928, and the results for the two nights agreed within $0^{s}.025$. The mean of the two determinations gave a difference of longitude from Washington of $5^{h}\ 23^{m}\ 11^{s}.884$. Using the 1926 value of the Washington longitude, this makes the longitude of the Honolulu station $10^{h}\ 31^{m}\ 27^{s}.635$ west, and the difference between Niu and Honolulu comes out as $32^{s}.353$. As stated on page 20, the old cable value for Honolulu, reduced to the 1926 value of the Washington longitude, is $10^{h}\ 31^{m}\ 27^{s}.699$ west.

RESULTS AT STATION FORT WM. McKINLEY (near Manila)

DESCRIPTION OF STATION

Longitude station Fort Wm. McKinley is about 6 miles southeast of Manila, P. I., in the grounds of the fort of the same name, on the east end of a spur, about 170 meters north of the officers' club in the eastern part of the reservation. The station is marked by a standard brass-disk triangulations tation mark which has the word "TRIANGULATION" in the inscribed legend changed to the words "WORLD LONGITUDE." The disk is set in the top of a concrete monument which tapers from 31 by 36 inches at the surface of the ground to 16 by 24 inches at the top. The monument is 46 inches high and extends 30 inches below the ground to "dobe" rock.

Local sidereal times of reception of radio signals

SIGNALS FROM HONOLULU, No. 17 (10.40–10.45; 37 METERS) [1]

Date, 1926	Local sidereal time		Date, 1926	Local sidereal time	
	Beat No. 1	Beat No. 306		Beat No. 1	Beat No. 306
	h. m. s.	h. m. s.		h. m. s.	h. m. s.
Nov. 22	22 47 39.703	22 52 40.512	Nov. 28	23 10 58.657	23 15 59.466
Nov. 23	50 33.859	55 34.668	Nov. 29	14 51.674	19 52.483
Nov. 24	55 26.354	23 00 27.163	Nov. 30	18 44.682	23 45.491

SIGNALS FROM SAIGON, NO. 19 (11.30–11.35; 15,800 METERS)

Date, 1926	Local sidereal time		Date, 1926	Local sidereal time	
	Beat No. 1	Beat No. 300		Beat No. 1	Beat No. 300
	h. m. s.	h. m. s.		h. m. s.	h. m. s.
Nov. 8	22 37 33.545	22 42 28.147	Nov. 18	23 19 54.340	23 24 48.945
Nov. 9	43 11.585	48 06.100	Nov. 19	24 22.048	29 16.638
Nov. 10	46 27.153	51 21.764	Nov. 22	36 17.757	41 12.362
Nov. 11	48 38.720	53 33.331	Nov. 23	39 23.658	44 18.212
Nov. 14	23 00 29.601	23 05 24.137	Nov. 24	44 03.269	48 57.877
Nov. 15	09 14.938	14 09.492			

SIGNALS FROM SAIGON, NO. 23 (19.00–19.05; 15,800 METERS)

Nov. 8	6 08 02.236	6 12 56.841	Nov. 19	6 55 13.956	7 00 08.537
Nov. 10	17 26.167	22 20.772	Nov. 24	7 14 20.072	19 14.656
Nov. 14	31 08.179	36 02.775			

[1] These short-wave signals were not used in computing the longtiudeof Fort Wm. McKinley. See p. 9.

COMPUTATION OF LONGITUDE, STATION FORT WM. McKINLEY

The computation of longitude at Fort Wm. McKinley was made in the same way as at station Niu (see p. 13) with the one exception, which has already been noted on pages 2 and 3. Because of the small number of observations at station Fort Wm. McKinley, differences with Niu, as well as with the two fundamental stations, Zikawei and San Diego, were used in deriving the final value of the longitude.

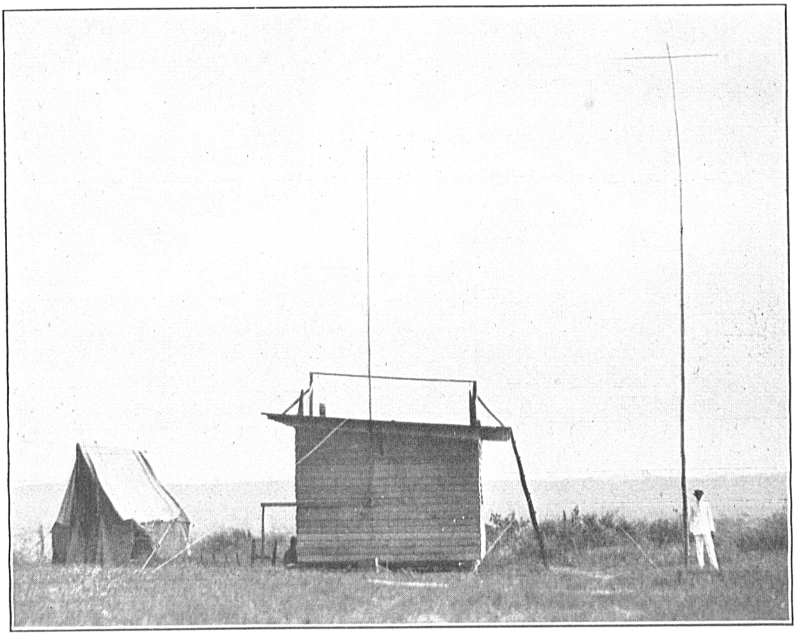

FIGURE 9.—OBSERVATORY AT FORT WILLIAM McKINLEY (NEAR MANILA)

This is on the military reservation about 6 miles southeast of Manila.

Comparison of local sidereal times at Niu and Fort Wm. McKinley

SAIGON SIGNALS NO. 19

Date, 1926	Sidereal time of 300th beat: Niu			Sidereal time of 300th beat: Fort Wm. McKinley			Difference, Niu minus Fort Wm. McKinley		
	h.	m.	s.	h.	m.	s.	h.	m.	s.
Nov. 8	4	07	20.203	22	42	28.147	5	24	52.056
Nov. 9		12	58.123		48	06.100			52.023
Nov. 15		39	01.630	23	14	09.492			52.138
Nov. 18		49	41.026		24	48.945			52.081
Nov. 23	5	09	10.353		44	18.212			52.141
Mean [1]							5	24	52.088

SAIGON SIGNALS NO 23

Date, 1926	Niu			Fort Wm. McKinley			Difference		
Nov. 19	12	25	00.709	7	00	08.537	5	24	52.172
Mean [2]							5	24	52.172

[1] Weight of this mean equals 5.

[2] Weight of this mean equals 1.

Comparison of local sidereal times at Fort Wm. McKinley and San Diego

SAIGON SIGNALS NO. 19

Date, 1926	Sidereal time of 300th beat		Difference, San Diego minus Fort Wm. McKinley
	Fort Wm. McKinley	San Diego	
	h. m. s.	h. m. s.	h. m. s.
Nov. 8	22 42 28.147	6 49 27.234	8 06 59.087
Nov. 9	48 06.100	55 05.077	58.977
Nov. 10	51 21.764	58 20.812	59.048
Nov. 11	53 33.331	7 00 32.293	58.962
Nov. 14	23 05 24.137	12 23.186	59.049
Nov. 15	14 09.492	21 08.523	59.031
Nov. 18	24 48.945	31 47.941	58.996
Nov. 19	29 16.638	36 15.691	59.053
Nov. 22	41 12.362	48 11.357	58.995
Nov. 23	44 18.212	51 17.300	59.088
Nov. 24	48 57.877	55 56.888	59.011
Mean [1]			8 06 59.027

[1] Weight of this mean equals 11.

Comparison of local sidereal times at Fort Wm. McKinley and Zikawei

SAIGON SIGNALS NO. 19

Date, 1926	Sidereal time of 300th beat		Difference, Zikawei minus Fort Wm. McKinley
	Fort Wm. McKinley	Zikawei [1]	
	h. m. s.	h. m. s.	h. m. s.
Nov. 8	22 42 28.147	22 43 58.43	0 01 30.283
Nov. 9	48 06.100	49 36.28	30.180 R [2]
Nov. 10	51 21.764	52 52.02	30.256
Nov. 11	53 33.331	55 03.52	30.189
Nov. 14	23 05 24.137	23 06 54.42	30.283
Nov. 18	24 48.945	26 19.16	30.215
Nov. 19	29 16.638	30 46.91	30.272
Nov. 22	41 12.362	42 42.64	30.278
Nov. 23	44 18.212	45 48.55	30.338 R [2]
Nov. 24	48 57.877	50 28.11	30.233
Mean [3]			0 01 30.251

[1] See footnote 1 on p. 14. [2] See footnote 2 on p. 14. [3] Weight of this mean equals 8.

Computation of transmission times

[See p. 10]

Longitude station	Radio transmitting station	Distance	Difference in distance	Correction for transmission time
		km.	km.	s.
Niu	Saigon	10,140		
Fort Wm. McKinley	do	1,700	+8,440	−0.028
San Diego	do	13,319		
Fort Wm. McKinley	do	1,700	+11,619	−0.039
Zikawei	do	2,110		
Fort Wm. McKinley	do	1,700	+410	−0.001

Differences of longitude

NIU TO FORT WM. McKINLEY

Radio signal	Computed difference of longitude	Weight	Correction for transmission time	Corrected difference of longitude
	h. m. s.		*s.*	*h. m. s.*
Saigon, No. 19	5 24 52.088	5	−0.028	5 24 52.060
Saigon, No. 23	52.172	1	−.028	52.144
Weighted mean				5 24 52.074
Probable error				±0.021

SAN DIEGO TO FORT WM. McKINLEY

Radio signal	Computed difference of longitude	Weight	Correction for transmission time	Corrected difference of longitude
Saigon, No. 19	8 06 59.027	11	−0.039	8 06 58.988

ZIKAWEI TO FORT WM. McKINLEY

Radio signal	Computed difference of longitude	Weight	Correction for transmission time	Corrected difference of longitude
Saigon, No. 19	0 01 30.251	8	−0.001	0 01 30.250

Least-squares adjustment

[Fixed differences of longitude are: San Diego to Zikawei (main polygon), $8^h\ 05^m\ 28^s.733$ and Niu to Zikawei (see p. 17), $5^h\ 23^m\ 21^s.825$]

Stations	Observed difference of longitude	Correction symbol	Weight	Least-squares correction	Adjusted difference of longitude
	h. m. s.			*s.*	*h. m. s.*
San Diego-Fort Wm. McKinley	8 06 58.988	v_3	11	−0.003	8 06 58.985
Zikawei-Fort Wm. McKinley	0 01 30.250	v_1	8	+.002	0 01 30.252
San Diego-Zikawei	8 05 28.738				8 05 28.733
Niu-Fort Wm. McKinley	5 24 52.074	v_2	6	+.003	5 24 52.077
Zikawei-Fort Wm. McKinley	0 01 30.250	v_1	8	+.002	0 01 30.252
Niu-Zikawei	5 23 21.824				5 23 21.825

Fixed difference, San Diego to Zikawei, minus observed difference equals $-0^s.005$, and fixed difference, Niu to Zikawei, minus observed difference equals $+0^s.001$.

Therefore,

$$v_3 - v_1 + 0.005 = 0$$

and

$$v_2 - v_1 - 0.001 = 0$$

or

$$v_3 = v_1 - 0.005$$

and

$$v_2 = v_1 + 0.001.$$

Taking the weights into consideration the quantity to be made a minimum is

$$8\ v_1^2 + 6\ v_2^2 + 11\ v_3^2.$$

Substituting the values of v_2 and v_3 above, this reduces to

$$8\ v_1^2 + 6\ (v_1 + 0.001)^2 + 11\ (v_1 - 0.005)^2.$$

Differentiating and equating to zero we obtain

$$16\ v_1 + 12\ v_1 + 0.012 + 22\ v_1 - 0.110 = 0,$$

$$v_1 = +0.002,$$

$$v_2 = +\ .003,$$

$$v_3 = -\ .003.$$

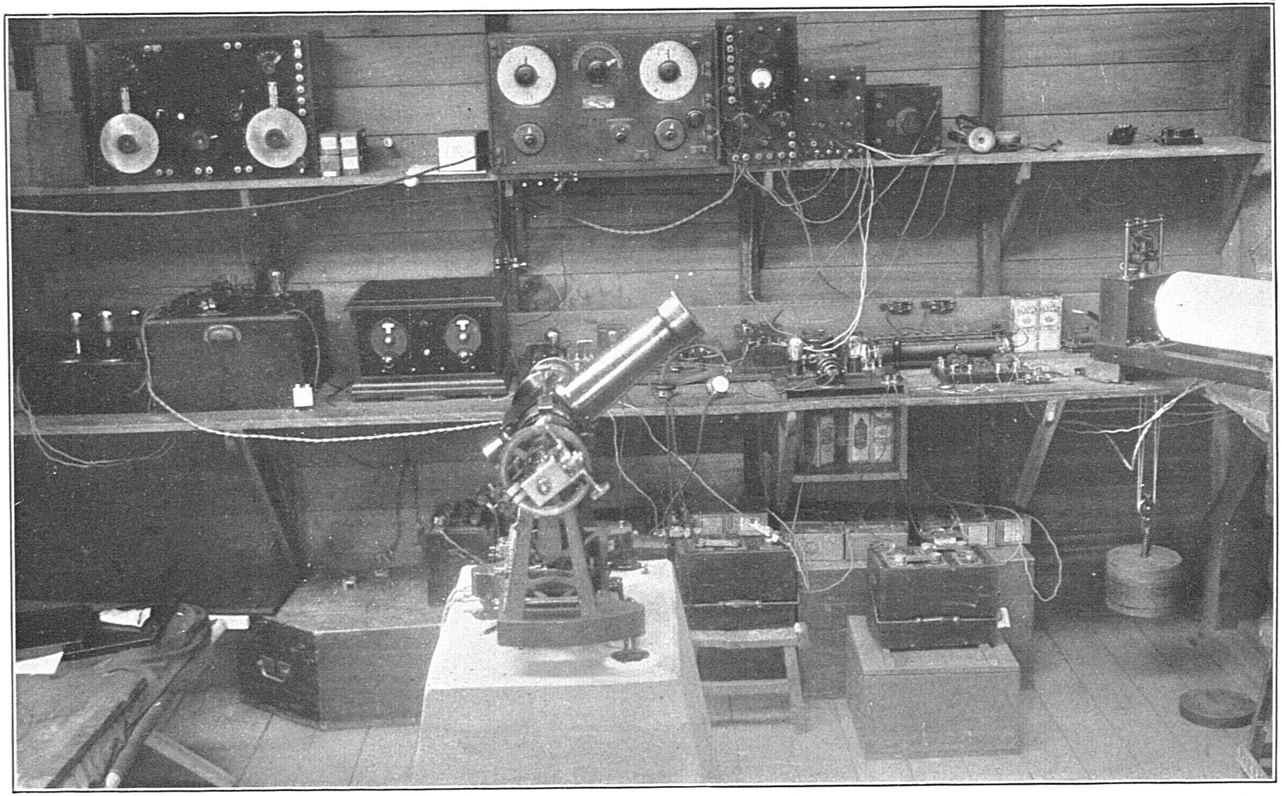

FIGURE 10.—INSTRUMENTAL EQUIPMENT AT FORT WILLIAM MCKINLEY

The transit is shown on the concrete pier near the center of the picture and the chronograph on the bench at the extreme right. The rest of the instruments are mostly radio equipment.

FINAL LONGITUDE

The longitude of Zikawei, as given in the publication referred to in the footnote on page 18, is 8^h 05^m 42^s.893 east of Greenwich, and the longitude of San Diego, as given in the same publication, is 7^h 48^m 48^s.374 west. Applying the adjusted differences given above, we obtain the following result for Fort Wm. McKinley: **Longitude of Fort Wm. McKinley = 8^h 04^m 12^s.641 east of Greenwich.**

The published value of Fort Wm. McKinley given in the publication referred to above is 8^h 04^m 12^s.656 east. As stated in connection with a corresponding discrepancy at station Niu (see p. 18), the difference of 0^s.015 is probably due to somewhat different methods for making rejections in the computations.

ASTRONOMICAL CONNECTION OF FORT WM. McKINLEY AND OLD CABLE STATION AT MANILA

During the spring of 1927 Lieutenant Sipe and Lieut. J. A. McCormick made an astronomical connection between the station at Fort Wm. McKinley and the old cable longitude station at Manila, which was determined in 1903. Lieutenant McCormick occupied the Manila station, using one of the old-type straight-telescope transits.

Longitude differences were determined on four different nights but the result for the last night had to be rejected. The following table contains the results for the other three nights:

Difference of longitude, Fort Wm. McKinley to Manila

Date, 1927	Longitude difference
	s.
Mar. 30	20.317
Mar. 31	20.308
Apr. 1	20.302
Mean	20.309
Probable error	±.003

The cable determination of 1903 gave the longitude of Manila as 8^h 03^m 52^s.202 east.[10]

This value is based on 5^h 08^m 15^s.784 west as the adjusted longitude of Washington. As stated on page 20, the 1926 radio determination of Washington is 5^h 08^m 15^s.751 west. Applying a correction to the old Manila longitude to take account of this change we obtain 8^h 03^m 52^s.235 east as the old cable value for Manila based on the new datum.

The adjusted longitude of Fort Wm. McKinley (see above) is 8^h 04^m 12^s.641 east. If we subtract from this the difference of longitude given above between that station and the Manila station, we obtain for the latter a value of 8^h 03^m 52^s.332 east. This gives a discrepancy of 0^s.097 between the old and new determinations. We can safely attribute a rather large percentage of this discrepancy to the cable determination because of errors inherent in that method. The

[10] See Coast and Geodetic Survey Special Publication No. 110, p. 40.

agreement between the two values is therefore about as close as could be expected.

DESCRIPTION OF OLD CABLE LONGITUDE STATION AT MANILA

The original description of the cable longitude station at Manila reads as follows: [11]

In the walled city of Manila, in the block fronting on Calle Audiencia, between Calle Postigo and Calle Claveria, and 9.48 meters from the house line on the first-named street. Station is in a quadrangle formed by the foundation of a projected government building (Spanish), and opposite the plaza in front of the government building commonly known as the Ayuntamiento. Two massive granite blocks were set for the instrument piers, their centers being in an east and west line and 5.5 feet apart. The eastern pier is the longitude station. Cathedral dome, a triangulation station, is 46.98 meters south and 100.67 meters east of the station.

When the station was recovered in 1927, there was only one granite pier standing. This was found to be the old longitude pier. Check measurements were made to the cathedral dome. The 1927 description states that the station is on the east side of a proposed palace building on Calle Gral. Luna, about 50 meters back from Calle Aduana and 10.65 meters from the sidewalk curb of Calle Gral. Luna. The station is marked by a granite block 4 feet high and 18 by 24 inches in cross section.

[11] See Coast and Geodetic Survey Special Publication No. 110, p. 278.

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