THE DETERMINATION OF SECONDARY MERIDIANS BY THE ELECTRIC TELEGRAPH.

by

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(Reproduction of the original article written by Commander F. M. GREEN, at the conclusion of the work of the expedition, kindly communicated by the courtesy of the U. S. Hydrographer.)

During the winter of 1872-73, the attention of Commodore R. H. WYMAN, U.S.N., Hydrographer to the Bureau of Navigation, was attracted to the rapid extension in every part of the world of the system of submarine telegraph-cables, affording the means of establishing secondary meridians of longitude with an accuracy attainable in no other way.

In the construction of new charts for the use of navigators, as well as in the correction of old ones, the assignment of different latitudes and longitudes to the same point by various authorities has always been a source of difficulty and embarrassment.

The exact position of all prominent points on the coasts of the United States, as well as those of England, France and other European nations, has been determined with great accuracy; but a large portion of the earth's surface is still very imperfectly and inaccurately laid down on marine charts.

Astronomical observations and hydrographic surveys are constantly being made, with a view to the correction of these errors; but, in order to work systematically and efficiently, it is exceedingly desirable to establish secondary meridians of longitude, measured with the utmost care and accuracy, from a primary meridian like that of Greenwich or Paris, and to which the longitudes of neighboring points can be easily referred by chronometric measurements (1).

With this object in view, the French Government in 1866 organized several parties, which, in the course of the next two or three years, visited many points in America, Polynesia, Japan, China and India, observing moon-culminations in order to permanently establish secondary meridians (2). This work was conceived and carried out before the present extension of telegraphic cables could be foreseen, otherwise it can hardly be doubted that the French astronomers would have waited till they could make use of the telegraphic method, so much easier, shorter and more accurate.

Prof. Asaph HALL, U.S.N., of the Naval Observatory, says:

"The trouble with moon-culminations is that there seem to exist, in the observations, constant errors which no amount of observing can get rid of.

"The real probable error of a longitude found by means of moon-culminations, under the best conditions, that is, when the moon is compared with stars at both stations, amounts to two or three seconds of time. In case the position of the moon is taken from an ephemeris, the error in longitude may

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(1) RAPER, *Practice of Navigation*, p. 380.
(2) *Revue Maritime et Coloniale*, 1868; *Connaissance des Temps*, 1870, 1871 (appendix).

be much larger, since, at the present time, the ephemerides computed from the best tables, those of HANSEN and PIERCE, are frequently in error by nearly a whole second of time.

"It should be noticed that the moon's motion among the stars being nearly thirty times slower than the rotation of the earth on its axis, an error in the observations or in the position of the moon will appear in the resulting longitudes multiplied by a factor nearly equal to thirty."

By means of chronometers transported across the Atlantic in numbers, as well as by observations of moon-culminations, occultations and eclipses, astronomers had sought to establish a secondary meridian at Washington, by measuring the difference of longitude between it and Greenwich, the most accurate possible determination of this difference being required by law of Congress; but the discordance of the results, which individually would have appeared entitled to full reliance, exceeds four seconds of time; the most recent determinations, and those which would have been more relied on, being among the most discordant. No amount of labor, effort or expense was spared by the United States Coast Survey for its chronometric measurements, and the thorough accuracy of Professor NEWCOMB'S investigations is well known to astronomers; yet the results of the latest chronometric expedition between England and the United States varies from the difference of longitude deduced by Professor NEWCOMB from moon-culminations observed at the Washington Observatory and compared with corresponding observations at the Greenwich Observatory by more than three and a half seconds of time (1).

For many years past, the officers of the United States Coast Survey and of the Corps of United States Engineers, as well as the astronomers on duty at the United States Naval Observatory, have been employed in simplifying and perfecting the methods of finding differences of geographical longitude by the electric telegraph and of determining geographical latitudes by the zenith-telescope.

The Coast Survey, with the aid of these methods, both of the greatest simplicity, has fixed the latitudes and longitudes of very many points on the coasts of the United States with a degree of accuracy previously unapproached in any work of the kind (2).

As soon as the Atlantic cable was successfully laid in 1866, the Superintendent of the Coast Survey promptly took advantage of the opportunity to connect the longitudes of the western hemisphere with the meridian of Greenwich by way of Ireland and Newfoundland.

In 1869-70, a similar determination was made by diffeient observers through the French cable from Duxburry, Mass., to Brest.

Again, 1872, a measurement was made through the same cable, using the island of Saint Pierre in the Gulf of Saint Lawrence as an intermediate station.

(1) Dr. B. A. GOULD'S *Report on Tran-Atlantic Longitudes*, 1869.
(2) Preface to CHAUVENET'S *Spherical and Practical Astronomy*.

The exquisite accuracy of the results of these measurements is demonstrated by their accordance. Referring them to the station of the New York City Hall, the resulting longitudes are as follows :—

New York City Hall west of Greenwich Observatory :

1866 :	4 h. 56 m. 1 s. 71	or	74° 0'25".65.
1869 :	4 h. 56 m. 1 s. 70	or	74° 0'25".50.
1872 :	4 h. 56 m. 1 s. 67	or	74° 0'25".05.

This method can, of course, only be used where telegraphic communication already exists ; but where circumstances admit of its use, there can be no doubt of its superior accuracy, simplicity, and facility.

Officers of the United States Navy may be gratified to remember that among the very first of the astronomers to successfully introduce this method was Captain J. M. GILLISS, U.S.N., who determined in this way the difference of longitude between Santiago and Valparaiso, Chile.

No systematic determinations of the latitudes and longitudes of the West India Islands, as a whole, have previously been attempted. Separate surveys of some of the islands have been made ; the longitudes being referred generally by chronometric measurement to the secondary meridian of Havana or Santa Cruz, which positions in their turn depended on observations and methods more or less untrustworthy, but the best attainable before telegraphic lines could be used.

In Martinique and Guadeloupe, the French surveyors determined their longitudes by moon-culminations, and it has been for years notorious that their longitudes and those of the neighboring English islands have not harmonized.

In 1868, a determination of the Havana longitude was made by an exchange of time signals between Prof. W. HARKNESS, U.S.N., at the Naval Observatory at Washington, and Lieutenant (now Captain) PUJAZON, of the Spanish Navy, at Havana (1).

The determination indicated an error of about one minute of longitude, but was not quite satisfactory, inasmuch as at the Havana end of the line the chronometer was carried every evening nearly a mile from the observatory to the telegraph-office and back again for comparison with the clock at Washington, instead of having the two observatories in telegraphic communication with each other ; and, moreover, the observers at Washington and Havana had no opportunity of meeting to establish their relative personal equation.

The longitudes of most of the Windward Islands have depended upon that of Majors LANG's Observatory at Santa Cruz (2). In his own words : "The longitude (64°41'0") is the result of the labor of years, and I consider it to be determined with such certainty that I do not think its error can

(1) Washington Observations, 1870, Appendix I.

(2) During the stay of the U.S.S. *Gettysburg* at Santa Cruz, in March 1876, the bearing and the distance of the observatory established there by Lieut. Comdr. GREEN were carefully measured for Major LANG's observatory, now in ruins.

exceed four seconds of time. I am induced to think it the most accurately determined position in the West Indies" (1).

The completion of the lines of the West India and Panama Telegraph Company in the spring of 1873, and the certainty that serious errors existed in the geographical position of many places in the West Indies and South America, caused Commodore WYMAN to submit to the Navy Department a plan for the outfit of an expedition which should seek to determine, with all possible accuracy, the latitudes and longitudes of points connected by telegraph in that part of the world.

Authority for the work was readily obtained from the Navy Department, and the directors of the telegraph company granted the use of their lines on most liberal terms, declining to accept any payment for messages sent in relation to the work or for the use of the wires after business hours, only stipulating that the operators or clerks should be recompensed for their attendance and assistance after the regular work of the day was over.

The lines of the West India and Panamà Telegraph Company, with those of the Cuba Submarine Company, afforded admirable facilities for longitude determinations. Extending from Guiana on the east, through the Windward and Virgin Islands, to Cuba and Jamaica, and thence to Aspinwall and Panama, trustworthy starting points for the longitudes of the west coasts of Mexico, Central America and South America could be established, as well as for Brazil and the north coast of South America; while intermediate determinations could be made at as many of the West India Islands as might be desirable and convenient.

The iron steamer *Fortune*, of 306 tons, was selected to transport the parties, and Lieut. Comdr. F. M. GREEN was ordered to command the expedition. After delays arising from various causes, the parties left the United States in November, 1874, returning in April, 1875, when, the *Fortune* being found too small for prolonged service at sea, the U.S.S. *Gettysburg*, a much more commodious vessel, was substituted for her.

Some improvements dictated by the first year's experience were made in the outfit, and the same officers sailed in the *Gettysburg*, in October, 1875, and, all the work assigned being completed, arrived at the Washington navy yard in June, 1876.

For determination of time and latitude, a combination of the transit-instrument and zenith-telescope was designed by Mr. J. A. ROGERS, and the construction of two of these instruments was commenced in the spring of 1873 at the repair-shop of the Hydrographic Office. These instruments were so constructed that the eye piece was at one end of the horizontal axis; a prism at the junction of the axis and telescope tube was reflecting at a right angle the rays from the object glass, thereby enabling the observer to direct the instrument upon stars of any altitude above the horizon without changing his position. These telescopes were of 30 inches focal length, and 2 3/4 inches clear aperture. Being mounted on a vertical axis, and having a 14 inch horizontal graduated circle, they could be readily turned 90° from the meridian

(1) *Nautical Magazine*, 1841.

into the prime vertical, a feature of very great importance for latitude determinations. The eye piece of each instrument was, during the first year's work, provided with eleven transit threads ; but, much annoyance arising from their breakage, they were, for the second winter's campaign, replaced by glass diaphragms, on which lines to take the place of transit threads were ruled with great accuracy by Mr. J. A. ROGERS, of Harvard Observatory.

A micrometer on the eye piece for measuring differences of zenith distances of stars, with a level attached to the axis to indicate any change in inclination of the telescope from the vertical, foımed the zenith telescope attachment for the determination of latitude.

These instruments were constructed with great care by Mr. Edward KAHLER, under the supervision of Mr. J. A. ROGERS, and were in all respects satisfactory.

Portable observatories were designed by Mr. ROGERS for sheltering the instruments and observers, and were most ingeniously constructed, so as to be easily and quickly set up and taken down.

Portable piers for mounting the transit instruments, made in the form of the frustum of a cone, out of heavy oak staves hooped strongly with iron, and to be filled with earth when in use, were furnished and were used at the first few stations. It was, however, found expedient to build brick piers, as their superior stability was found to warrant the trouble and delay attending their erection.

Four break circuit chronometers, of admirable accuracy, were furnished by Messrs. T.S. and J. D. NEGUS, of New York. These chronometers were adjusted to keep sidereal time, and were furnished with an attachment by which a toothed wheel on the arbor of the second's wheel came in contact every second with a small spring, thus breaking an electric circuit in which the chronometer was placed.

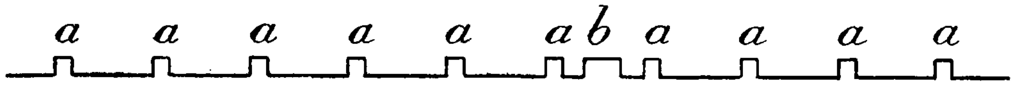
One of these chronometers for use, and one spare one in case of accidents, were furnished to each party.

For the registering of the times of transit of stars, or the occurrence of time signals, an electric chronograph was furnished to each party.

During the first season's work, an ordinary Morse register was used for this purpose ; but, before going out a second time, two beautiful cylinder chronographs, constructed by Messrs. William BOND and Son, of Boston, were purchased.

In these instruments, a train of wheel work driven by a weight caused a cylinder about 6 1/2 inches in diameter and 7 inches long, and covered with a sheet of paper easily put on and taken off, to make exactly one revolution in a minute.

A little carriage, to which a pen of peculiar construction is attached, moves upon wheels along the cylinder in the direction of its length, about one-tenth of an inch for each revolution of the cylinder, so that the pen records a perpetual spiral. The pen is so mounted as to have a slight lateral movement, and is so attached to an electro-magnet that when the electric circuit in which it is placed is broken every second by the chronometer, which, with a small battery, is included in the same circuit, the mark made on the chronograph paper, instead of being a straight line, will be broken at regular intervals, as shown at *a*.



By means of a little instrument called a break circuit key, in the hands of the observer and included in the same circuit, the electric current may be interrupted, causing the pen to make a similar mark as shown at *b* on the occurrence of any event, such as the passage of a star across any of the wires of the telescope.

When the sheet on the cylinder becomes full, it is taken off, and by means of a finely divided scale the positions of these arbitrary marks, with reference to the nearest second marks, may be accurately and easily determined.

A screw at the bottom of the pendulum affords an easy method of regulating the clock work, either for faulty running or for change of latitude.

The batteries used during the first season were formed by plates of carbon and zinc, partially immersed in dilute sulphuric acid contained in a glass jar. This arrangement was not satisfactory, as the battery was very variable in strength; and the second season each party was supplied with a twelve-cell Leclanché battery, two cells of which were used for the chronograph, and as many of the remaining cells as was necessary were used to establish communication through the cables between the observatories.

This battery gave no trouble, and was ample in strength.

The telegraph instruments used during the first season were borrowed from the West India Telegraph Company; but for the next year's work two sets of reflecting galvanometers, keys and lamps were procured from London.

Upon land lines, the time signals received can be recorded automatically by putting the chronograph into the telegraphic circuit; but with submarine cables the electric impulse transmitted is not strong enough to act upon the electro-magnets of the chronograph pen.

For telegraphing with weak impulses over submarine lines, a very beautiful device was invented by Sir William Thomson and is now in general use.

To a delicately suspended magnet, surrounded by one or more coils of fine, insulated wire, a small mirror is attached. From this mirror, a beam of light from a lamp is reflected on a scale in a dark room, so that, when no currents are passing through the cable, the beam remains at rest; but when at the sending station either of two keys is pressed, a positive or negative current, as the case may be, is sent through the cable and through the coil surrounding the magnet, causing the mirror to turn on its vertical axis and to deflect the ray of light to the right or left.

When the signal arrives and is received, the observer touches his chronograph key, thus recording the time of its arrival.

Throughout the two years' work, the same general system was pursued; the two observatories, with their instruments and outfits precisely alike in every particular, being under the especial charge of Lieut. Comdr. Green and Mr. Miles Rock, with Lieut. J. A. Noris and Mr. C. W. Bartlett, U.S.N., as assistants.

Mr. Rock had for several years previously been employed at the observatory at Cordova, and to his skill and indefatigable industry the success of the expedition is in a great measure due.

The work of 1875 comprised the measurements from Panama to Aspinwall; from Aspinwall to Kingston, Jamaica; Kingston to Santiago de Cuba; Santiago de Cuba to Havana; and Havana to Key West, there connecting with a carefully determined Coast Survey station.

In 1876, the measurement was commenced at Kingston and carried directly to St. Thomas; then from St. Thomas to Antigua; St. Thomas to Port Spain, Trinidad; Port Spain to Barbados; Port Spain to Martinique; St. Thomas to San Juan, Porto Rico; and a double measurement between St. Thomas and St. Croix, the observers and instruments at each place during one measurement being transferred to the other for the second determination. This was done as one method of determining the personal equation between the observers.

In selecting a site for the observatories, it was necessary to bear in mind the following desirable conditions, viz: a firm foundation; an unobstructed north and south view; facility of measurement to some permanent and easily distinguished landmark to which the latitude and longitude could be referred; proximity to the telegraph office, so that too much wire should not be required to connect with the observatory; and seclusion from crowds of inquisitive idlers.

Thanks to the cordial and zealous assistance everywhere extended, these requisites were found much more easy of attainment than had been hoped.

A surveyor's compass was found to be sufficient for determining an approximate meridian line for use in setting up the observatory and building the pier.

Two or three days having been allowed for the pier to harden, the transit instrument was set up and and carefully leveled.

During the first ensuing clear evening, it was placed accurately in the meridian by repeated observations of zenith and circumpolar stars. (1)

The telegraph instruments being set up and connected in each place with the telegraph office, so that direct telegraphic communication was established between the observatories, and everything being in readiness, the routine was as follows:

About 6 p.m., messages were exchanged as to clearness of sky and, if clear at both places, work was commenced about 8 p.m. by observing the transits of six or eight *Nautical Almanac* time stars, not far from the equator, and two or three circumpolar stars. At a time previously agreed upon, generally from half past 9 to 10 p.m., the wires from the observatory were connected at the telegraph office with the main line, and one of the operators came to the observatory at each place to assist in sending messages. Communication being established, the chronometers at the stations were compared in the following manner:

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(1) Chauvenet's *Spherical and Practical Astronomy*, vol. ii, p. 142; United States Coast Survey Professional Papers. Determination of Time, Latitude and Azimuth. Washington, 1876.

At ten seconds before the completion of a minute by his chronometer, the senior observer sent a rattle or preparatory signal by tapping his key several times in quick succession, then exactly at the even minute pressing his key again for about a quarter of a second and repeating this signal at intervals of five seconds till the completion of the next even minute.

The hour and minute when the first signal was sent were then telegraphed to the receiving station and repeated to insure correctness. The time of arrival of these signals, marked by the deflection of the ray of light from the galvanometer, was recorded by the chronograph at the receiving station and five similar sets were sent from each observatory to the other, making sixty-five signals sent and received by each observer.

After these exchanges of signals, five or six more time stars and two or three circumpolars were observed, completing the night's work.

The position of the axis of the transit instrument was reversed at least once every night, to facilitate the elimination of the error of collimation, and the level was applied and read after each star.

The errors of the chronometers on local time as derived from the star observations at each place, being applied to the difference of their faces, as shown by exchange of time signals, obviously give the exact difference of the true time of the two stations, or, in other words, their difference of longitude (1).

A great number of observations of various kinds were also made to determine the different instrumental constants.

After four or five nights of longitude work, zenith telescope observations of pairs of stars were made on four nights at each place, for latitude.

The time occupied by an electric impulse to traverse the wire from one station to another and act upon the telegraph instruments is, though generally very small, too great to be neglected, but is easily ascertained and allowed for.

Suppose *E* to be a station one degree of longitude east of another station *W*; and that at each station there is a clock exactly regulated to the time of its own place, in which case the clock at *E* will be of course four minutes fast of the clock at *W*; let us also suppose that a signal takes a quarter of a second to pass from one station to the other:

Then if the observer at *E* sends a signal to *W*	
at exactly noon by his clock	12 h. $0^m\ 0^s.00$
it will be received at *W* at....................	11 h. $56^m\ 0^s.25$
showing an apparent difference of time of....	$3^m 59^s.75$
Then if the observer at *W* sends a signal at	
noon by his clock..................................	12 h. $0^m\ 0^s.00$
it will be received at *E* at....................	12 h. $4^m\ 0^s.25$
showing an apparent difference of time of....	$4^m\ 0^s.25$

(1) CHAUVENET'S *Spherical and Practical Astronomy*, vol. i, p. 341.

One half the sum of these differences is four minutes, which is exactly the difference of time, or one degree of longitude; and one half their difference is twenty five hundredths of a second, the time taken by the electric impulse to traverse the wire and telegraph instruments.

This is technically called the "wave and armature time" and, between the stations in the West Indies, varied from seven hundredths of a second between Havana and Key West, connected by ninety miles of submarine cable, to forty-four hundredths of a second between Kingston and St. Thomas, connected by seven hundred and twenty miles of cable and thirty miles of land line.

The "wave and armature time" differs somewhat between the same stations on different nights, owing to variations in the conductivity of the lines and in the strength of the batteries.

Some English astronomers have objected that where the line is, as is usual in long land lines, divided into lengths connected by telegraphic repeaters, the time of transmission will not be the same in both directions and that the same effect would be produced in a submarine cable having an imperfection or leak nearer one end than the other. Experiments, however, by the Coast Survey on the long land line from Washington to San Francisco indicate that this objection, however well founded in theory, has no practical importance.

In exchanging time signals, positive currents were invariably used, to guard against any possible difference of velocity as compared with negative currents. This course had the additional advantage that one sending key was constantly used and the deflection of the ray of light at the receiving station took place always in the same direction.

In this way, during the winters of 1874-75 and 1875-76, the work of establishing eleven secondary meridians was completed. In every place, the site of the transit pier was referred, by careful measurement and triangulation, to some fixed and prominent landmark and care was taken to have one observer as often east as west of the other, in order to eliminate personal equation as far as possible.

Observations for the determination of personal equation between the observers were carefully made in various ways and no pains were spared to make the results of the work trustworthy and satisfactory.

The computation of the observations has been carried on as rapidly as opportunity would permit, and theresults will be published as soon as practicable.

The method of "star signals", or the comparison of the times at which the same star passes over the meridian of the two stations, is seldom used now and therefore need not be described in detail (1).

Although the naval surveyors of nearly all maritime nations, particularly the English, are constantly at work perfecting our knowledge of the earth's surface, it is believed that this is the first systematic naval expedition for establishing by this method secondary meridians to which other longitudes may be referred.

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(1) CHAUVENET'S *Spherical and Practical Astronomy*, vol. i, p. 342.

It is the present intention of the United States Navy Department, as expressed in the report of the Secretary of the Navy for 1876, to continue and extend these observations ; but the vast and constantly increasing net work of cables, nearly surrounding the earth, will afford work for many years to come and will, in a way hardly contemplated by the projectors, add in a very great degree to accurate geographical knowledge.