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The "American Method"
The 19th-Century Telegraphic Revolution in Finding Longitude

By Trudy E. Bell

135 years ago today, on July 27, 1866, a lone officer of the United States Coast Survey stood at Heart's Content, Newfoundland, anxiously watching the end of the 1866 transatlantic telegraph cable being hauled out of the ocean from the *Great Eastern* anchored offshore. As soon as he had ascertained that the signals were sharp, he telegraphed his superiors. Within days, the Coast Survey had dispatched astronomers and transit telescopes to both ends of the cable—Newfoundland and Valencia, Ireland.

Why was the U.S. Coast Survey—responsible for accurately charting and mapping the United States' thousands of miles of shoreline and waterways—so interested in a submarine telegraph cable between Ireland and Canada?

Abundant documentary evidence suggests that the telegraph may have been as revolutionary for determining longitude on land as Harrison's marine chronometer was for finding longitude at sea. The telegraphic method of determining longitude reigned in both the United States and Europe for eight decades, being replaced only in the 1920s by radio positioning techniques. Yet its history appears to have been largely overlooked—and certainly no mention of it appears in either of two recent popular-level bestsellers on the chronometer and the telegraph: Dava Sobel's *Longitude* or Tom Standage's *The Victorian Internet*.

Background: Demand for longitude determinations

Determining longitude was essentially determining a difference in *local time* between the instant a celestial body transits the local meridian of an unknown point and the instant it transits the meridian of a reference location. Recall that in the 1840s, 40 years before the adoption of standard time, clocks in each city were set to local solar time: local noon was the instant the real sun transited the meridian of the town's observatory or other significant landmark.

Until the telegraph, there was no *direct* way to compare differences in local time between places hundreds of miles apart. Expeditionary astronomers, surveyors, and ex-

plorers used the same indirect method as mariners: physically transporting chronometers set to the local time of a reference longitude, which could be compared with local times at unknown longitudes as determined by meridian transits. But geodesy demands far greater accuracy and precision than open-ocean navigation, and the rates of the delicate chronometers were altered unknown amounts by temperature changes or jostling on horseback.

The seemingly-instantaneous transmission speed of telegraph signals, however, promised to allow local clocks hundreds of miles apart to be compared in what today would be called real time—with (in the words of one contemporary) "the same degree of precision as if [the two clocks] were placed side by side." Beckoned by that prospect, whither the telegraph went, astronomers immediately followed, from the first land line to the first transatlantic cable.

Evolution of timing techniques

The telegraphic method of determining differences in longitudes was actually several methods, which evolved within the telegraph's first five years.

Three were techniques for comparing local times with varying rigor, which subsequently became standard to use in tandem [Fig. 1].

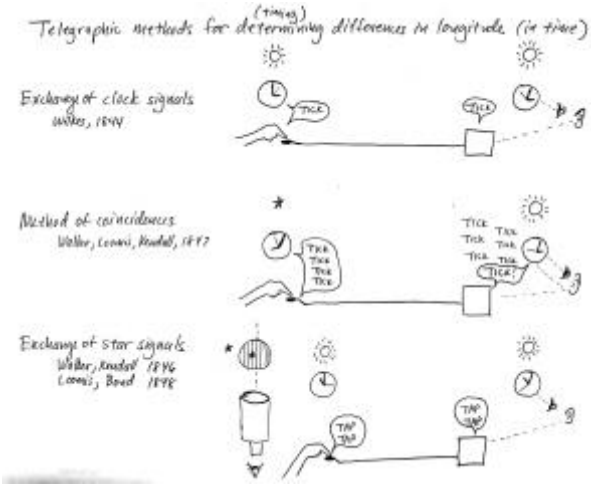

Fig. 1—Summary of three timing methods used in tandem (in order of invention and of use)

Exchange of clock signals

The first technique was an "exchange of clock signals," used on the experimental line between Baltimore and Washington, D.C., on June 9, 1844—just 2½ weeks after Morse's inaugural message "What hath God wrought?"

For three days, chronometric expert Commodore (later Admiral) Charles Wilkes and an associate took turns comparing two solar chronometers set to the respective local times of the two cities. One observer tapped the telegraph's battery key once every 10 seconds in time to the beats of his chronometer. Forty miles away, the other noted on the face of his own chronometer the instant he heard the corresponding click of the armature of his receiving electromagnet, estimating fractions of a second. After several minutes of 10-second signals, the first would communicate the exact local hour, minute, and second at which the beats had commenced. Assuming an instantaneous transmission time, subtracting the two local times would give the minutes and seconds difference of longitude between the two telegraph offices. The mean of all the observations was taken to be the longitude difference between the cities.

Although some later writers dismissed Wilkes's experiment as "crude," an exchange of clock signals became standard for quickly narrowing longitude differences to within a second of time.

Method of coincidences

After Wilkes's pioneering experiment for the U.S. Navy, the U.S. Coast Survey took the lead. As soon as commercial telegraph lines linked offices in major cities, the Coast Survey paid to have additional wires extended to astronomical observatories, and contracted with local astronomers or sent trained observers equipped with the agency's own transit telescopes.

To remove the error inherent in estimating fractions of a second in an exchange of clock signals, the "method of coincidences" technique was developed in July and August of 1847, when the Coast Survey measured longitude differences between the U.S. Naval Observatory in Washington, D.C., the Philadelphia Central High School Observatory, and a temporary observatory in Jersey City, N.J.

An astronomer at one end of the line tapped a telegraph key each second in time to his *sidereal* clock; at the other end of the line a second astronomer listened to the clicks of his armature magnet alongside the beats of his own *solar* chronometer. Since a sidereal clock gains upon a mean solar clock one second in about six minutes, whenever the two ticked in exact coincidence, the listener noted his local solar time. After several such coincidences, the second astronomer began beating and the first astronomer began listening. Within half an hour, the longitude difference could be calculated accurate to within the clock errors and reaction times.

Exchange of star signals

In 1848, a third technique called the "exchange of star signals" was refined when the Coast Survey used a telegraph line between Cambridge, Mass., and New York City on seven nights to determine the longitude difference between the Harvard College Observatory and the private observatory of Lewis M. Rutherford. Each observer tapped on a telegraph key each time a pre-selected star near the zenith was seen to cross each of the seven wires in the eyepiece of a transit telescope. The local solar time of the star signals from each observatory was noted at *both* observatories, the time difference yielding the longitude difference. Pairs of stars were used so the differences in local times were independent of any uncertainties in the known celestial positions of the stars.

All three techniques—exchange of clock signals, method of coincidences, and exchange of star signals—were used in October, 1848 to determine the difference in longitude (some 37 minutes of time) between Philadelphia and the Cincinnati Observatory 700 miles west, a new distance record. By the end of that year, the Coast Survey's superintendent Alexander Dallas Bache declared in his annual report that the telegraphic method of determining longitude "may be considered to have passed into one of the regular methods of geodesy."

Evolution of paper-recording techniques

But Bache's deputy in charge of telegraphic longitude determinations, Sears Cook Walker, was troubled by there being no permanent record of a longitude determination.

Now, the history of the chronograph (the recorder for telegraphic longitude determinations) is murky with nasty controversy over priority of invention, which is beyond the scope of this paper on fundamental measurement techniques. But two central technical issues are clear.

One primary difficulty was connecting an astronomical clock to a recording device without degrading the precise time-keeping of the clock. The other was getting the recording device itself to function with precise uniformity.

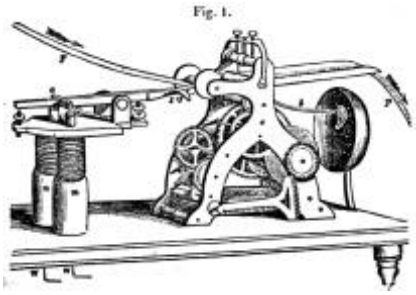

Fig. 2—Morse register with fillet

Locke's Morse fillet

For recording star signals and clock signals at a distance, Cincinnati instrument-maker John Locke was the first to try using the Morse register used for printing telegraph messages on a long fillet, or paper tape [Fig. 2].

In a seminal experiment on the night of January 23, 1849, a clock of Locke's design was set up in the Philadelphia observatory and connected to the respective observatories in Cambridge, New York City, and Washington, D.C. The star signals telegraphed from each observatory were recorded on Morse fillets at all four observatories along with the time ticks from the Philadelphia clock. Fractions of a second could be measured at leisure by scale and dividers.

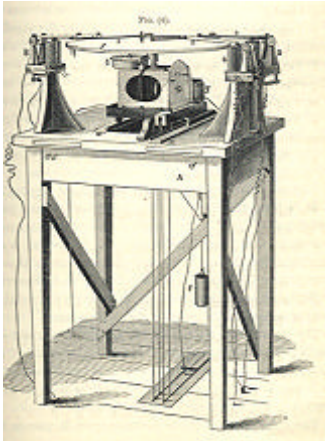

Fig. 3—Mitchel's revolving-disk

Mitchel's revolving-disk chronograph

Although the Morse fillet was used in several early longitude determinations, astronomers quickly rejected it as the ultimate. First, the fillet ran irregularly depending on whether or not the pen was writing. Worse, the fillet ran out of the register at an inch a second, so a night's worth of longitude determinations spewed out close to half a mile of paper tape—impractical for storage or analysis.

In 1849, Cincinnati Observatory director Ormsby McKnight Mitchel developed a revolving-disk chronograph, somewhat anticipating the form of an oversized 20th-century phonograph record [Fig. 3]. A flat disk 22 inches in diameter—made by pasting a sheet of paper over a circular wooden hoop, which dried to become as taut as a drumhead—revolved horizontally once per minute. A make-circuit clock marked every other second with a tiny dot. At the end of every revolution, the disk's position was shifted by 0.07 inch. Two hours of observations were recorded on each flat circular sheet, on which alternate seconds appeared as radial dotted lines and observations as dots irregularly in between [Fig. 4].

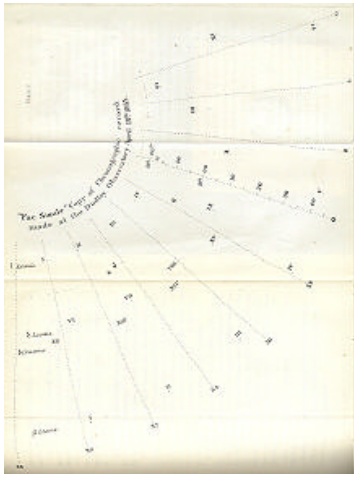

Fig. 4—Mitchel disk chart.

At least two of Mitchel's revolving-disk chronographs were placed in actual operation, one at the Cincinnati Observatory itself

and the other at the Dudley Observatory in Albany, N.Y.

The Bonds' spring-governor chronograph

In 1850, Harvard College Observatory director William Cranch Bond and his sons unveiled a cylindrical chronograph. The cylinder, covered with a large rectangular sheet of paper, revolved once per minute and measured time as a continuous line that was offset momentarily by each tick of an astronomical clock [Fig. 5]. The cylinder revolved and the paper advanced with uniform motions controlled by an ingenious break-circuit regulator they called a spring governor, consisting of a train of clockwork connected with the axis of a flywheel. Each sheet of the Bonds' spring-governor chronograph recorded two hours of observations. Ultimately, the Bonds' design became standard for chronographs used in most 19th-century observatories.

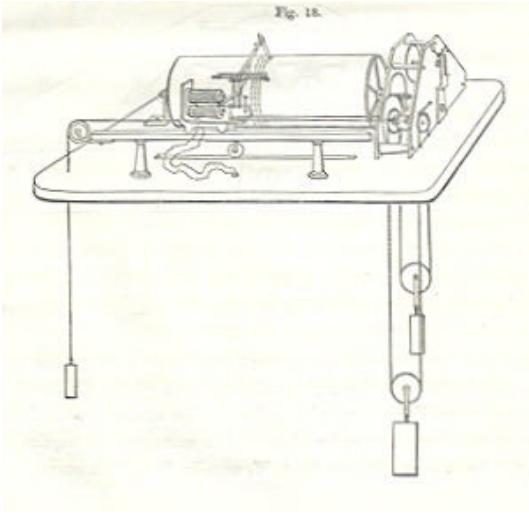

Fig. 5—Bond spring-governor chronograph

The "American method"

With the addition of a method of permanently recording observations, the telegraphic method of determining longitudes was essentially complete. The technique won immediate accolades and adoption across the Atlantic, and rapidly became known as the "American method" in contemporary literature. In fact, it was one of the first major contributions of the American scientific community to worldwide astronomical practice.

Determining global longitude

By the mid-1850s, the Coast Survey had telegraphically determined geodetic baselines extending from New Orleans, Louisiana to New Brunswick, Canada [Fig. 6], most referred to the meridian of the U.S. Naval Observatory. Still lacking, however, was a definitive reference of all U.S. longitude measurements to the meridian of Greenwich, England.

The long-awaited telegraphic opportunity was finally at hand with the connection of first successful transatlantic cables in July and September, 1866. By October, the Coast Survey had built temporary astronomical observatories at both Heart's Content and Valencia. An observer at one end eyeballed deflections of a pencil of light thrown onto a screen by a delicate mirror galvanometer to indicate when the astronomer at the opposite end beat the seconds of his local solar clock [Fig. 7].

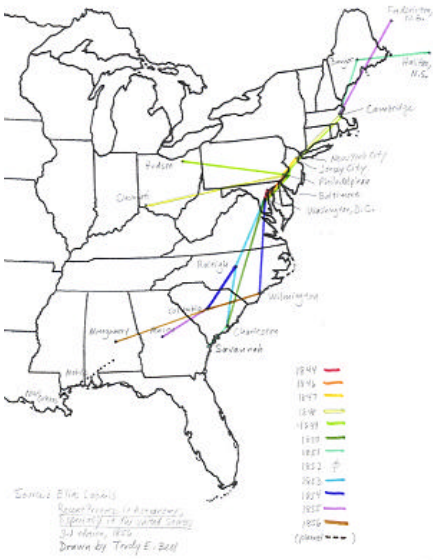

Fig. 6—Cities whose longitudes were telegraphically determined 1844-56.

From October 24 through November 20, 1866, clock

signals were exchanged on five nights using both the 1865 and 1866 cables, yielding the first directly-measured longitude of the dome of the U.S. Capitol west of the Greenwich Observatory: 5 hours 8 minutes and 2.22 seconds.

That was the good news. The bad news was that the signal-transmission methods essentially turned the cables into giant capacitors, whose discharge rate affected the signal transmission times. So the first word was not yet the last.

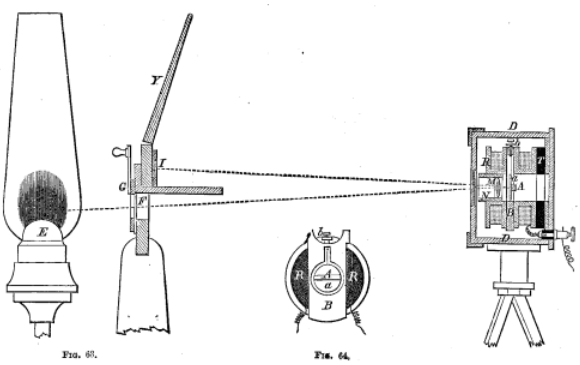

Fig. 7—Mirror-galvanometer method used to detect clock signals (and other telegraphic transmissions) on the trans-Atlantic cable, to determine the longitude of Washington, D.C. west of Greenwich, 1866.

Epilogue

As ambiguous as the first transatlantic telegraphic determination of longitude may have been, by 1866 the telegraph had bequeathed far more to astronomy than precise longitude measurements.

Perhaps its greatest contribution was the American method of *transits* for nightly astronomical data recording. In the last half of the 19th century, observatories worldwide installed internal telegraph systems in what today would be called a local-area data network, centrally recording time signals along with the observations of astronomers manning several telescopes. The telegraph and chronograph also inspired astronomers' first experiments to quantify personal equation.

Moreover, applying the telegraph to geodesy unwittingly furthered basic science. In a classic case of serendipity, the four Morse fillets from the January 1849 experiment of simultaneously registering clock and star signals at four observatories revealed "small, but appreciable, differences… in the respective readings of the apparent date of the same event as recorded at the different stations." The farther an observatory was from the graduating clock at Philadelphia, the greater was the discrepancy. In short, Walker stumbled onto the discovery that electromagnetic signals were not instantaneous, as had hitherto been supposed, but had a finite and measurable velocity through a circuit.

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References (N.B. I could not get Microsoft Publisher to show the actual footnote numbers!!)

Benjamin Apthorp Gould, "The Transatlantic Longitude, as Determined by the Coast Survey Expedition of 1866. A Report to the Superintendent of the U.S. Coast Survey." *Smithsonian Contributions to Knowledge* No. 223 (vol. XVI, article VII). City of Washington: Smithsonian Institution, 1870. p. 2.

Dava Sobel's *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time* focuses on Harrison, inventor of the first reliable marine chronometer, ending 50 years before the invention of the telegraph. Tom Standage's *The Victorian Internet: The Remarkable Story of the Telegraph and the Nineteenth Century's On-line Pioneers* covers the right 19th-century time period, but focuses exclusively on the telegraph as a traditional communications medium, omitting all uses of it that we would now call "data communications" (e.g., using the telegraph for municipal fire alarm systems, etc.). The only book I'm aware of that mentions aspects of the telegraphic method of determining longitudes is Ian Bartky's *Selling the True Time: Nineteenth-Century Timekeeping in America* (Stanford University Press, 2000), which is primarily concerned with 19th-century observatories' use of the telegraph in operating time services and time balls, activities that shared some technology in common.

For a complete history of local time vs. standard time, see Michael O'Malley, *Keeping Watch: A History of American Time,* Smithsonian Institution Press, Washington, D.C., 1990.

Loomis, *Recent Progress*, ibid., p. 310.

Wilkes had been a former superintendent of the Navy's Depot of Charts and Instruments (predecessor of the U.S. Naval Observatory and the Department of Hydrography), where, among other things, he had established rigorous, standardized procedures for rating and testing chronometers. Accounts differ as to who was Wilkes's associate. Cincinnati Observatory director Ormsby McKnight Mitchel cites "Mr. Vail" (Samuel F. B. Morse's business partner Alfred Vail; see "Differences of Longitude by Magnetic Telegraph—Details of Work for Obtaining the Longitude of the Cincinnati Observatory—U.S. Coast Survey," [unsigned, but clearly by Ormsby McKnight Mitchel], *Sidereal Messenger*, vol. 3, no. 1, p. 7, September, 1848 while University of the City of New York professor Elias Loomis cites a "Lieutenant Eld" (see Loomis, *The Recent Progress of Astronomy; Especially in the United States* (New York: Harper & Brothers, third edition, 1856), p. 304). Actually, both Vail and Eld could have been there simultaneously or on different days, as Mitchel's own various published accounts for the Cincinnati longitude determination give a different roster of observers at the Cincinnati Observatory in October, 1848. That being said, Eld seems the most likely to have done the actual work, as he had been Wilkes' right-hand associate in many of the magnetic and other scientific observations during the U.S. Exploring Expedition 1838-42, and "in all these duties he was known for his skill and fidelity" (see the obituary "17. Lieut. Henry Eld, Jr., U.S.N.," *American Journal of Science*, series 2, vol. 10, 1850, p. 137). I have been unable to locate any primary account by Wilkes of his pioneering Washington-Baltimore longitude determination, although secondary articles by Mitchel, Elias Loomis, Walker, and others provide some details.

The exact technique for exchanging clock signals is detailed in Loomis, *op. cit.*, p. 307-8.

The U.S. Naval Observatory was manned by three astronomers, including Sears Cook Walker, former acting director of the Philadelphia Central High School Observatory who had had a keen interest in the computation of longitude from astronomical observations since the 1830s. The Philadelphia High School Observatory was manned by Walker's brother-in-law, the observatory's director E. Otis Kendall. The temporary astronomical observatory at Jersey City was manned by University of the City of New York professor Elias Loomis, who had already logged years of astronomical longitude observations in the 1830s as director of the Hudson Observatory in Ohio. Why Jersey City? Because until submarine cables were perfected, the Hudson River formed an effective barrier to extending reliable telegraph lines directly to New York City for many years.

Then and now, astronomers use two types of clocks. Mean solar clocks measure 24 hours from one meridian transit of the sun at noon to the next. (The mean sun is the average position of the sun in the sky assuming constant angular motion throughout the year, as if the earth were traveling in a circular orbit whose center were the sun. In reality, of course, the sun's apparent [real] position in the sky—as revealed by a sundial, for example—actually

varies throughout the year as the result of the earth's speeding up and slowing down as its elliptical orbit carries it alternately closer and farther from the sun [which is at one focus] throughout the year. See O'Malley, op. cit., for detailed explanations about what this meant for time-keeping.) Sidereal clocks measure 24 hours from one meridian transit of a star at midnight to the next. Since each day the earth advances in its orbit around the sun, a 24-hour sidereal day is almost four minutes shorter than a 24-hour solar day. If a sidereal clock and a mean solar clock are placed side by side, they tick exactly together—in coincidence—once in every six minutes, at a moment whose time can be accurately calculated. Actually, the coincidences happened about every three minutes, since most 19th-century solar chronometers beat twice a second. See Loomis, *op. cit.*, p. 308.

The Harvard College Observatory was manned by its director William Cranch Bond, renowned for building chronometers and other instruments; Lewis M. Rutherford observatory—at what was then the rural uptown location of Second Avenue and 11th Street (now part of the Big Apple's lower east side)—was manned by Loomis.

Loomis, *op. cit.*, pp. 310-311.

Quoted in *The Coast Survey, 1807-1867* (Volume I of the History of the Commissioned Corps of the National Oceanic and Atmospheric Administration), by Captain Albert E. Theberge, NOAA Corps (Ret.) http://www.lib.noaa.gov/edocs/BACHE2.htm, p. 6 of 38. This 623-page online book, heavily footnoted, is a detailed and lively account of the Coast Survey under Hassler and Bache. The title page is at http://www.lib.noaa.gov/edocs/TITLE.htm and the table of contents is at http://www.lib.noaa.gov/edocs/CONTENTS.htm#CONTENTS .

In 1860, Cincinnati Observatory director Ormsby McKnight Mitchel recalled, "On the 26th of October, 1848, Professor Walker…first presented to me the mechanical problem of causing the clock to send its own beats by telegraph from one station to the other." If clock beats "could be received on a uniformly flowing time scale, the star transit could also be sent by telegraph and received on the same scale; and thus a new method of transits would at once spring from the resolution of the first mechanical problem." Walker mentioned to Mitchel that he had also presented the problem to others, "but so far as he knew, [it] had never been solved." Recounted in Mitchel's *Popular Astronomy*, New York: Phinney, Blakeman & Mason, 1860, p. 235.

This problem occupied the attention of Harvard College Observatory director and instrument-maker William Cranch Bond, Cincinnati Observatory director Ormsby McKnight Mitchel, Coast Survey instrument-maker James Saxton, and half a dozen others, who sought to make the connection by methods ranging from the mechanical (fine wires, human hairs, spider webs) to the electromagnetic.

Locke was subsequently awarded $10,000 by U.S. Congress for the invention and directed to build such a clock for the U.S. Naval Observatory, which was installed in 1850. See Loomis, *Recent Progress*, *op. cit.*, pp. 322-323, 330.

Loomis, Recent Progress, p. 331.

Loomis, *op. cit.*, p. 327.

This description of Mitchel's revolving-disk chronograph is synthesized from Mitchel's *Popular Astronomy*, op. cit., pp. 243-44 and from the *Annals of the Dudley Observatory*, vol. 1 (Albany, N.Y.: Weed, Parsons & Co., 1866), pp. 33-40.

Annals of the Harvard College Observatory, (Cambridge: Metcalf & Co., 1856) vol. 1, part 1, p. xxvii.
One significant later modification was the practice of having observers switch sites midway through a series of observing nights to cancel most effects of their respective "personal equations" or reaction times. Loomis, *op cit.*, pp. 340-41.

One example is the talk presented before the Royal Astronomical Society on December 14, 1849 by the Astronomer Royal of the Royal Greenwich Observatory, George Biddell Airy, which began: "The Americans of the United States, although late in the field of astronomical enterprise, have now taken up that science with their characteristic energy, and have already shewn their ability to instruct their former masters." See Airy, "On the Method of observ-

ing and recording Transits, lately introduced in America; and on some other connected subjects,” *Monthly Notices of the Royal Astronomical Society*, vol. 10, p. 26, 1849. I am indebted to Professor Rand Evans, Department of Psychology, East Carolina University, for pointing out this connection.

Marc Rothenberg, “Sears Cook Walker,” *American National Biography*, 1999, vol. 23?, p. 514.

Years of independent transatlantic longitude determinations from moon culminations, lunar occultations, and chronometric expeditions disagreed with one another by a good four seconds of time, 20 to 30 times worse than any telegraphic uncertainty on U.S. land. See Gould, *op. cit.*, pp. 5, 1.

Because of the weak voltages over such an unprecedented length of cable, no register was connected at either end for automatically recording the signals.

An exchange of star signals was impractical not only because of the three-hour wait for stars transiting the Valencia meridian to reach the meridian of Heart’s Content, but also because of the persistently miserable weather at both sites. It rained in Ireland for weeks straight, and “it was an event of frequent occurrence for the observer to be disturbed by a copious fall of rain while actually engaged in noting the transit of a star.” Thus, transit telescopes were used only to nail down local times. See Gould, *op. cit.*, p. 9. Other experiments were conducted as well to determine the velocity of the signals over such an unprecedented distance, as well as to quantify the observers’ personal equations. Additional clock and star signals were exchanged at intermediate telegraph stations for another few thousand miles down both sides of the Atlantic from Valencia to Greenwich and from Heart’s Content to Washington, D.C.

ibid., p. 80. Since only clock signals were exchanged by hand and eye, I find this a striking historical parallel to Wilkes’ pioneering experiment with the telegraph’s first land line 22 years earlier.

ibid., p. 101.

For example, the Harvard College Observatory installed such a system in 1859. See *Annals of the Astronomical Observatory of Harvard College*. Vol. VIII. Part I. 1876. p. 21ff. With such a system, an astronomer simply tapped a telegraph key each instant a star crossed a vertical wire in a transit telescope or meridian circle, instead of listening to clock ticks and counting seconds and calculating the delay in looking at a clock face to write down the time. Thus, astronomers quickly realized they could put not just seven widely spaced vertical wires, but dozens of finely-spaced wires in a transit telescope’s field of view, eliminating the need for multiple nights of observation to attain the same precision. The telegraph as electromagnetic observing assistant increased the precision and productivity of the work by—according to contemporary estimates—a factor of between four and ten, meaning they could produce star catalogues that much faster. Moreover, the “de-skilling” of such observations meant they could now be farmed out to relatively inexperienced observers.

Simon Schaffer, "Astronomers Mark Time: Discipline and the Personal Equation," *Science in Context*, vol. 2 (1988): 115-45. The telegraph also provided steady income to astronomical observatories from selling accurate local time signals—and later standard time signals—to railroads; see Bartky and O’Malley, *op. cit.* in the most sophisticated setups, the observatory’s telegraph signals actually adjusted a railroad station’s clock remotely. The telegraph was also used on solar eclipse expeditions seeking the hypothetical inner planet Vulcan: if observers in a western part of the path of totality thought they spotted Vulcan, they were to telegraph its observed position to colleagues waiting farther east.

“Telegraphic Operations of the Coast Survey.—Velocity of the Galvanic wave,” *American Journal of Science*, series 2, volume 8, 1849, p. 143-4. From the four fillets, Walker calculated the velocity to be 18,800 miles per second—a speed subsequently much debated and revised but of the right order of magnitude.