The Victorian Global Positioning System

by Trudy E. Bell

STARS GLEAMED OVERHEAD in a velvet-black sky on a crisp October night in 1848 as six astronomers entered the darkened dome of the three-year-old Cincinnati Observatory. Seating themselves around a table laden with several large batteries and clocks, Ormsby McKnight Mitchel, the observatory's director, was keenly aware of the moment's historic significance. About 9 p.m., the men were joined by a telegraph operator who, Mitchel wrote,

> . . . perfected the necessary arrangements for communicating directly by telegraph between the Cincinnati Observatory and the Philadelphia [Central High School] Observatory. At ten o'clock the way offices along the line were closed, and the line of the telegraph given up to the use of the astronomers. The novelty of the operations excited the deepest interest among all who were present. …
>
> At a quarter past ten, the compliments of the astronomers in the two observatories were passed. Cincinnati then asked Philadelphia, "Are you all ready?" The answer came back instantly, "Aye! Aye! O.K., go ahead." Cincinnati then directed Philadelphia to send her clock signals. The answer was—"All right, look out for gong signal"—the signal well understood by both parties, and which precedes each important communication. … All was instantly quiet. In about half a minute, the well known gong signal sounded, and after the lapse of half a minute more, we heard the swing of [Philadelphia's] sidereal clock pendulum, every vibration giving us a tick. And thus did it swing, beating seconds for fifteen consecutive minutes.
>
> … Now, Philadelphia did not undertake to transport her sidereal clock to Cincinnati, that its beats might be compared with our mean solar chronometer, but with the potent (I almost said *omnipotent*) aid of magnetism, this comparison is virtually and absolutely effected at the distance of seven-hundred miles.

The telegraph was as revolutionary for determining longitude on land as the marine chronometer was for finding longitude at sea. Along the way, the telegraph also reformed observational astronomy and nationwide time-keeping.

With this vivid account, published immediately in the Cincinnati Observatory's periodical *The Sidereal Messenger*, Mitchel affords an eyewitness's glimpse into one of the great untold stories in the histories of telegraphy, astronomy, and geodesy: the telegraphic method of determining longitudes.

Within a few short years, the telegraph had transformed both positional astronomy and geodesy. The telegraphic method of determining longitudes held sway for eight decades not only in the United States but also in Europe—being replaced only in the 1920s by radio (wireless) positioning techniques. Yet its history appears to have been largely overlooked, including in two recent popular bestsellers on the measurement of longitude and on the telegraph.[1]

WHY A DEMAND FOR LONGITUDES?

In the fewer than four years between the installation of the first electromagnetic telegraph (May 1844) and the cry of *"Gold!"* from Sutter's Mill (January 1848), the already-vast continental United States grew another 50 percent by several fast, enormous gulps of territory. By the time of the Cincinnati-Philadelphia longitude determination, the nation spanned from Atlantic to Pacific with essentially the same boundaries it has today—most of it trackless wilderness.

Now, it's tough to develop, defend, mine, govern, or tax millions of square miles of uncharted land. So the U.S. Army, state governmental agencies, and commercial concerns hired astronomers, topographers, and geologists to mark legal boundaries, map natural resources, ascertain military routes, divide arable lands into salable township squares, and survey routes for the tracks of the new-fangled "iron horse" locomotives. Moreover, with all the new territories came thousands of miles of uncharted coastlines, whose collective hazards annually wrecked scores of ships with uncounted losses of cargo and human life. Accurate maps were badly needed of harbors, shoals, and inland waterways—the mission of the U.S. Coast Survey, chartered by President Thomas Jefferson in 1807.

In short, in the burgeoning westward-expanding nation, latitude and longitude determinations were big business.

Determining latitude was straightforward. At the instant a star of known celestial position transited (crossed) the local meridian (imaginary north-south line passing through the observer's zenith), an observer measured its altitude above the local southern horizon—or, after the introduction of the Talcott method in the 1830s, its angular distance down from the local zenith. A lone observer could do with satisfactory accuracy even in the remote wilds with a portable transit telescope (a telescope constrained to move only in the plane of the observer's meridian [Fig. 1]).

Determining longitude, however, was challenging. Because of the rotation of the earth, a difference in longitude is equivalent to a difference in *local time*: that is, the difference between the instant either the sun or a star crossed the local meridian of an unknown place and the instant it crossed the local meridian of a reference location.

Now, recall that when the telegraph was invented, time zones and standard time were still 40 years off in an unknown future. In the 1840s, clocks were set to each town's own individual local solar time—that is, local noon was the moment the real sun transited the local meridian of some astronomical observatory or significant landmark in town.[2] Thus, longitude differences were equivalent to differences in the time on local clocks separated by some distance east and west.

Until the advent of the telegraph, however, there was no *direct, instantaneous* way to compare clocks at places hundreds of miles apart. The only method was indirect, cumbersome, and subject to lengthy delays: physically transporting a chronometer reading the local time of a reference longitude to a place of unknown longitude and comparing its time with the local time as determined by meridian transits of the sun or stars. This was not just a matter of packing an additional pocket watch. Chronometers were bulky and expensive precision instruments, carefully cushioned in bread-loaf-sized waterproof wooden boxes that had to be hand-carried when on the backs of spirited horses. As insurance, field astronomers, surveyors, and topographers routinely toted three or more chronometers—some actually took more than a dozen. Still, despite every pain, they often found their chronometers had "tripped" because of temperature changes or jostling, jeopardizing the precision of painstaking longitude calculations.

The telegraph transformed all that. The seemingly-instantaneous speed of what Mitchel heralded as the telegraph's "omnipotent magnetism" effectively annihilated distance, allowing two clocks 700 miles apart to be compared virtually as if they were sitting side by side, in what today would be called "real time."

Lured by that beckoning promise, whither the telegraph went, field astronomers followed, from the first land line to the first transatlantic cable—just as quickly as arrangements could be made and transportation allowed.

MANUAL TIME-COMPARISON TECHNIQUES

The telegraphic method of determining differences in longitudes was actually several methods, all of which evolved within the telegraph's first five years. There were three techniques for measuring differences in local times, which subsequently became standard to use in tandem.

EXCHANGE OF CLOCK SIGNALS

The earliest technique was a direct, manual comparison of two chronometers set to the local solar time of the cities at each end of the telegraph line. It relied on

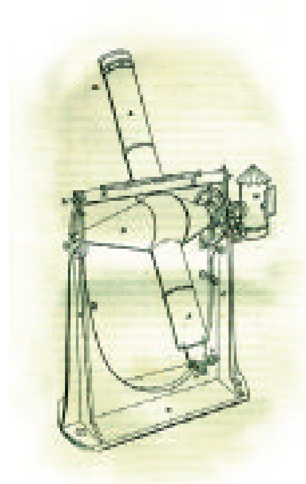


Figure 1
A typical 19th-century portable astronomical transit telescope for measuring latitudes and longitudes from the sun and stars was mounted so as to confine its observations to the meridian—the imaginary line running from due north to due south through an observer's zenith. The main telescope tube *AA* was supported on a perpendicular axis *BB* that rested in Y's fixed to the uprights *CC* as part of a single-piece stand of cast iron. Near the right end of the axis was a graduated circle *G* that turned with the axis; the circle's angular measurements, indicating the altitude to which the telescope was elevated, were read by a stationary vernier *H*.

At the telescope's focus were crosshairs [see Fig. 7] that at night were faintly illuminated by the lamp *M* to make them visible against the dark sky.

[Elias Loomis, *An Introduction to Practical Astronomy* (New York: Harper & Bros., 5th edition, 1863), p. 40]

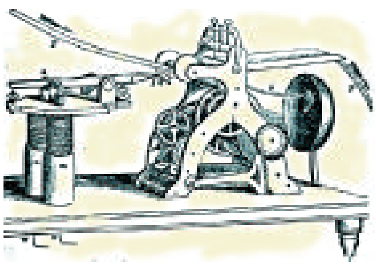


Figure 2
A Morse register was the standard apparatus at 19th-century telegraph offices for recording messages. When a telegraph key was depressed, an electromagnet *mm* attracted the armature *a*, causing lever *l* to pop upward and press steel pen point *s* against the fillet (paper tape) *p* running uniformly through the register at about an inch a second. When the telegraph key was released, the spring-loaded lever popped back down to its resting position, releasing the pen point from the fillet. In this way, dashes or dots and spaces could be recorded quite rapidly on the moving fillet. (In the 19th century, the design of the Morse register went through many variations to improve speed, accuracy, and reliability, so several different designs may actually have been used for early longitude determinations.)

[Charles T. Chester, "On the Electric Telegraph of Prof. Morse," *American Journal of Science and Arts*, 2nd series, vol. 5, no. 13 (January, 1848), p. 56]

skilled observers' eyes, ears, hands . . . and patience.

On June 9, 1844—just two weeks after Samuel F.B. Morse's inaugural Biblical quotation "What hath God wrought?" flashed 40 miles along the first experimental telegraph wire between Washington, DC, and Baltimore—Commodore (later Admiral) Charles Wilkes and an associate stepped into the same two telegraph offices. Wilkes, famous for recently leading the U.S. Exploring Expedition 87,000 miles around the Pacific Ocean (1838-42), was one of the nation's foremost chronometric experts; as former superintendent of the U.S. Navy's Depot of Charts and Instruments (predecessor of the U.S. Naval Observatory and the Department of Hydrography), he had established rigorous, standardized procedures for rating marine chronometers. Now, in this first-ever telegraphic-longitude experiment, Wilkes set one man's chronometer accurately to the local time of the Battle Monument in Baltimore and the other to the local time of the Capitol building in Washington.

For three days, Wilkes and his associate took turns. At one end of the telegraph line, one watched his chronometer and tapped the telegraph's battery key every 10 seconds in time to the beats of its pendulum. Forty miles away at the other end of the line, the second observer noted on the face of his own chronometer the instant he heard the corresponding click of the armature of his receiving electromagnet, doing his best to estimate fractions of a second. At the end of several minutes of 10-second signals, the first observer would communicate the exact local hour and minutes at which the beats had been sent. Assuming an instantaneous transmission time, subtracting the two local times would give the minutes and seconds difference of longitude between the two locations. Then it was the turn of the second observer to send similar clock signals back to the first, *ad infinitum*. The mean of all the observations was taken to be the exact longitude. After three days of observations, Wilkes calculated that the Battle Monument of Baltimore was one minute 34.87 seconds east of the Capitol in Washington.[3]

Although some later 19th-century writers dismissed Wilkes' experiment as "crude," his technique—dubbed the "exchange of clock signals"—became standard for quickly determining longitude differences to within a second of time.

EXCHANGE OF STAR SIGNALS

After Wilkes' pioneering proof of the concept for the U.S. Navy, the U.S. Coast Survey took the lead. Within months of Wilkes' experiment, the survey's superintendent, Alexander Dallas Bache—who grew to be a towering figure in 19th-century American science—officially indicated his interest in the possibilities of the method. But it was another two years before enough commercial telegraph wire had been installed to offer actual opportunities. From then on, as soon as commercial telegraph lines linked offices in major cities, the Coast Survey paid to have additional wires extended to each city's astronomical observatory; it then contracted with local astronomers (or sent its own trained observers equipped with the survey's own transit telescopes) to determine differences in longitude.

The first opportunity arose in the fall of 1846. The Coast Survey arranged to link the U.S. Naval Observatory in Washington with the Philadelphia Central High School Observatory and a temporary astronomical observatory in Jersey City, NJ, on the western bank of the Hudson River. For this experiment, the aim was to determine differences in longitude not only by comparing chronometers, but also by using stars themselves as keepers of each site's local time. Although technical difficulties prevented Jersey City from making it into the loop, on October 10 and 22, 1846, Philadelphia and Washington were finally in successful communication, and clock signals were exchanged to compare the approximate local times (just as Wilkes had done two years before).

Then for the first time, on the evening of October 10, an astronomer tapped a telegraph key each time a pre-selected star near the zenith was seen to cross each of the seven vertical wires (crosshairs) in the eyepiece of a transit telescope. The local solar time of each signal was noted at both observatories, the time difference yielding the longitude difference.

That technique of "*sending* star signals," however, was subject to any errors in the celestial position determined for the star. To eliminate such errors, the star-signals technique was refined two years later. In the summer of 1848, the telegraph was used on seven nights to determine the difference in longitude between the Harvard College Observatory in Cambridge, MA, and the brand new private observatory of Lewis M. Rutherford in New York City. This time, pre-selected *pairs* of zenith stars were used, with both observatories noting the local times of each *pair* of signals—in this way, differences in local times were independent of the stars' absolute celestial positions. Moreover, the pairs were selected so that both stars transited Cambridge's meridian before the first star reached New York's meridian about 12 minutes later.

This final refinement, known as the "*exchange* of star signals," immediately became a standard technique.

METHOD OF COINCIDENCES

Meanwhile, a third timing technique using better telegraphic apparatus was developed in July and August of 1847 in a this-time-satisfactory repetition of the Washington-Philadelphia-Jersey City experiment. After a few nights of exchanging clock signals, the parties hit upon an ingenious method of removing the error intrinsic in estimating fractions of a second by ear: they would compare *two types* of chronometers beating at slightly different rates.

Astronomers use two types of clocks. A solar clock counts 24 hours for the period of the earth's rotation measured by the sun (essentially, the time between meridian transits from one noon to the next). A sidereal clock, on the other hand, counts 24 hours for the period of the earth's rotation measured by the stars (essentially, from a meridian transit of a star one night to its transit the next).

But the two 24-hour days are not the same length. In fact, the sidereal day is three minutes 56 seconds shorter than the solar day, because during a day the earth has also progressed along its orbit, changing the position of the sun with respect to the background stars. Thus, a sidereal clock gains upon a mean solar clock one second in about six minutes. So if a sidereal clock and a solar clock are placed side by side, they tick exactly together once about every six minutes, at a moment whose time can be accurately calculated. (Actually, since most 19th-century solar chronometers beat twice a second, the coincidences happened every three minutes.)

How did the two different astronomical clocks increase the precision of longitude determinations? An astronomer at one end of the line tapped a telegraph key each second in time to his *sidereal* clock, while a second astronomer at the other end of the telegraph line listened to the clicks of the armature magnet along with the beats of his *solar* chronometer. When 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.

In half an hour of monotonous beating and listening, this so-called "method of coincidences" allowed the two stations to compare their local times, and thus their longitudes, accurate to within the clock errors.

All three techniques—exchange of clock signals, exchange of star signals, and method of coincidences—were first tried in the summer of 1848 to determine the differences in longitude between New York City and Cambridge. That October 1848, they were used to determine the difference in longitude between Philadelphia and the Cincinnati Observatory 700 miles west, setting a new distance record.

By the end of the year, Bache declared in his annual report of the superintendent of the Coast Survey that the telegraphic method of determining longitude "may be considered to have passed into one of the regular methods of geodesy."

AUTOMATED RECORDING TECHNIQUES

But Bache's deputy in charge of telegraphic longitude determinations, Sears Cook Walker, was troubled. He knew that all three telegraphic techniques suffered from two sources of human error: the sender's imperfect imitation of a clock beat and the recipient's imperfect noting of the beat's arrival. Moreover, Walker was uncomfortable with there being no permanent record of a longitude determination—a concern he mentioned to any astronomer who would listen.

Now, the history of recording devices for telegraphic longitudes is murky with nasty controversy over credit and priority of invention, which are beyond the scope of this brief history of measurement techniques. But the central technical issues and their major resolutions are clear.

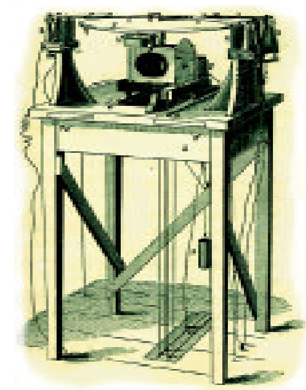


Figure 3
In the revolving-disk chronograph (top) designed by Ormsby McKnight Mitchel, Cincinnati Observatory director, a make-circuit clock marked every other second with a tiny dot. At the end of every revolution, the disk's position was shifted by 0.07 inch. Two hours of observations could be recorded on each circular sheet, on which alternate seconds appeared as radial dotted lines and observations as dots irregularly in between (bottom).

[*Annals of the Dudley Observatory*, vol. I (Albany, N.Y.: Weed, Parsons & Co., 1866), p. 33 and opposite p. 40.]

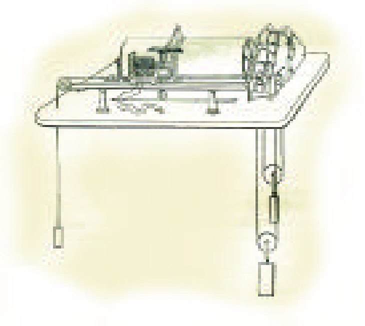
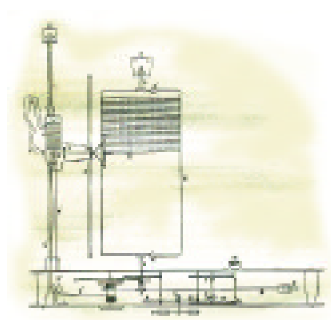


Figure 4
In the cylindrical chronograph (above) designed by Harvard College Observatory director William Cranch Bond, a cylinder covered with a large rectangular sheet of paper revolved once per minute; an ink-filled glass pen marked time as a continuous line that was offset momentarily by each tick of an astronomical clock. Both the cylinder's uniform speed of revolution as well the paper's horizontal advance were controlled by a novel break-circuit machine the Bonds called a spring governor, which consisted of a train of clockwork connected with the axis of a flywheel (housed between the trapezoidal panels). The marked sheet (below), when taken off the cylinder, had the minute columns nearly vertical (being slightly spiral on the cylinder) with the seconds marked off horizontally on each minute scale. As with Mitchel's disk, each 13-inch-long rectangular sheet contained two hours of observations.

[*Annals of the Harvard College Observatory*, (Cambridge: Metcalf & Co., 1856) vol. 1, part 1, pp. l and lii.]



One major question was how to connect an astronomical clock to a recording device without degrading the precise time-keeping of the clock. Harvard College Observatory director and instrument-maker William Cranch Bond, Cincinnati Observatory director Mitchel, Cincinnati instrument-maker John Locke, Coast Survey instrument-maker James Saxton, and various other people experimented with methods ranging from fine wires, human hairs, spider silk, and sweeps of the pendulum through globs of mercury to electromagnetic induction (the ultimate winner).

The other primary difficulty was getting the recording device itself to function with precise uniformity.

Locke was the first to try using the fillet (paper tape) of a Morse register standard at telegraph offices for recording messages [Fig. 2]. In a seminal experiment on the night of January 23, 1849, a clock that Locke designed was set up in the Philadelphia observatory and connected by telegraph to the respective observatories in Cambridge, New York City, and Washington, DC. When an astronomer at any one observatory tapped a telegraph key as a star transited his local meridian, the star signals were telegraphically recorded at all four observatories.

The result was four long rolls of paper tape—one each at Cambridge, New York, Philadelphia, and Washington, DC. All were graduated into equal parts by the ticking of the Philadelphia clock and were printed with the instants the star was seen to pass each wire of the transit telescope at each observatory. The position of each printed mark permanently recorded the fraction of a second.

Not only was this experiment an effective proof of the viability of telegraphically registering astronomical observations—it also turned out to be a classic case of serendipity. When Walker measured the four fillets for the times of the star signals relative to the clock signals from Philadelphia, he was surprised to note "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. These differences, Walker reported,

> *may all be explained by the hypothesis that the time of propagation of the galvanic wave from the place of the clock or star signal stations, to that of the receiving register, though small, is not quite insensible.* [5]

In other words, Walker had stumbled onto the discovery that an electromagnetic signal was not instantaneous, as everyone had supposed, but had a finite and measurable velocity through a circuit—which he calculated to be 18,800 miles per second (a speed later much measured, debated, and revised).

Although the Morse register served as either a primary or backup recorder in several early longitude determinations, astronomers quickly rejected it as the ultimate solution. For one thing, the fillet ran irregularly, depending on whether or not the pen was writing. Worse, since the fillet ran out of the register at an inch a second, a mere hour of longitude determinations spewed out more than 300 feet of paper tape and a night's work close to half a mile—impractical for useful storage or subsequent analysis.

Cincinnati Observatory director Mitchel developed a flat disk 22 inches in diameter made by pasting a damp sheet of paper over a circular wooden hoop, which dried to become as taut as a drumhead. The disk revolved horizontally once per minute, anticipating the form of an oversized 20th-century phonograph record [Fig. 3]. 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, NY.

Meanwhile, Harvard College Observatory's director Bond at Cambridge, along with his two instrument-making sons, pursued designs for a cylindrical chronograph [Fig. 4]. Eventually they succeeded in overcoming two challenges—making both the cylinder revolve and the paper advance with uniform motions—using a novel break-circuit machine they called a spring governor, which consisted of a train of clockwork connected with the axis of a flywheel. Ultimately, the Bonds' cylindrical spring-governor design became the standard for chronographs adopted by most 19th-century observatories.

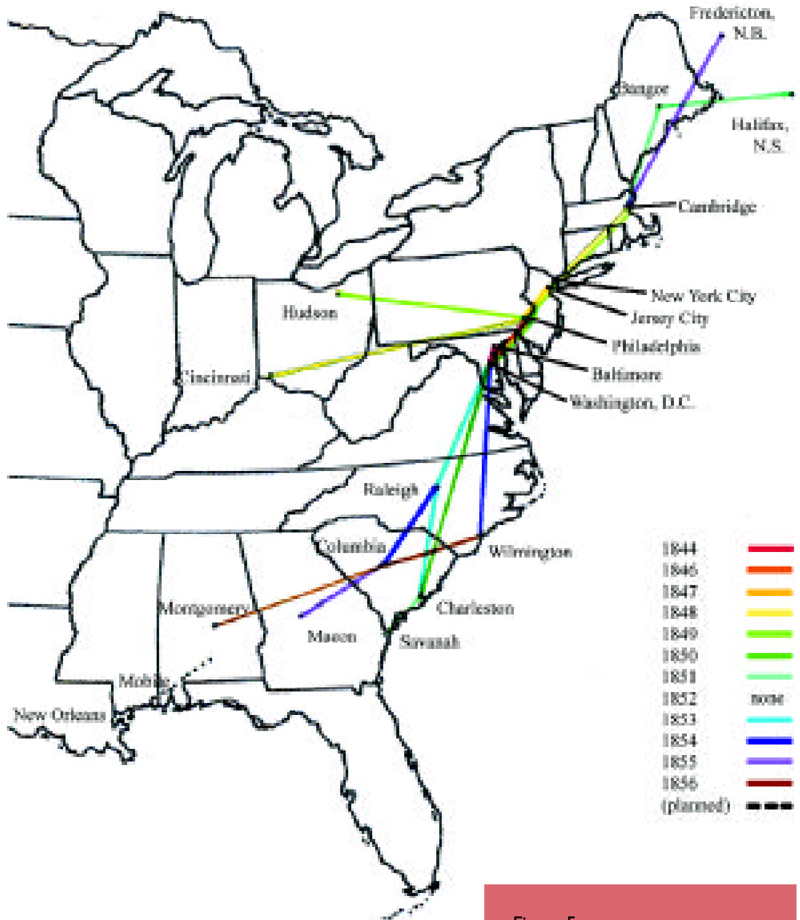


Figure 5
Between 1844 and 1856, the U.S. Coast survey had telegraphically determined primary geodetic baselines between astronomical points of geodetic significance, had linked the American system of longitudes with key British points in Canada, and had plans for further expansion in the south (dashed lines). For their fundamental reference meridian, most observations used either the Harvard College Observatory in Cambridge, MA, or the U.S. Naval Observatory in Washington, DC.
(In actuality, the baselines were not ruler-straight, but followed the routes of the telegraph wires—and some observations were cross-checked over two different routes.)

[Map designed by Trudy E. Bell from historical data in Chapter IV of Elias Loomis, The Recent Progress of Astronomy; Especially in the United States *(New York: Harper & Brothers, third edition, 1856)]*

THE "AMERICAN METHOD"

With the addition of apparatus for permanently recording observations, the telegraphic method of determining longitudes was essentially complete. (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.)

The technique won immediate accolades from high places and adoption on the other side of the Atlantic. Before the Royal Astronomical Society on December 14, 1849, George Biddell Airy, the Astronomer Royal of the Royal Greenwich Observatory, kicked off a speech by stating: "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." Thereafter, the telegraphic method of determining longitudes became widely known as the "American method," [6] one of the first major contributions of the American scientific community to worldwide astronomical practice.

DETERMINING GLOBAL LONGITUDE

By 1856, the Coast Survey had telegraphically determined geodetic baselines extending from Montgomery, AL, to New Brunswick, Canada [Fig. 5], 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, thereby linking astronomical and geodetic determinations in the New World with those made in the Old.

This wasn't for lack of trying. Astronomers on both sides of the Atlantic had logged decades of independent determinations from half-a-dozen types of astronomical observations—such as lunar occultations (eclipses of stars by the moon) and lunar and solar eclipses—whose timings could be compared from both sides of the Atlantic. Even more ambitious, between 1849 and 1851, the Harvard College Observatory launched two Grand Chronometric Expeditions, sending scores of chronometers by ship back and forth *19 times* across the Atlantic and comparing them with reference chronometers in Boston and Liverpool. Despite all pains, all the various independent longitude determinations disagreed with one another by a good four seconds of time—a substantial fraction of a mile, and 20 to 30 times worse than any telegraphic uncertainty on U.S. land.

So it was with anticipation that on July 27, 1866, a lone Coast Survey officer stood on the windswept beach of the fishing village Heart's Content, Newfoundland, watching the end of a telegraph cable being hauled out of the ocean. Offshore was anchored the *Great Eastern*, which had just completed its two-week voyage laying the 1852-mile single length of telegraph cable from Valencia, Ireland. Just as soon as the cable's electrical connections were complete and the officer had ascertained that the signals were sharp, he telegraphed his superiors. Within days, the Coast Survey had dispatched astronomers and transit telescopes to both sides of the Atlantic as fast as steam ships and overland conveyances could travel.

An exchange of star signals was deemed impractical because of the nearly three-hour wait for stars transiting the Valencia meridian to reach the meridian of Heart's Content. Moreover, the persistently miserable weather in both Newfoundland and Ireland—during

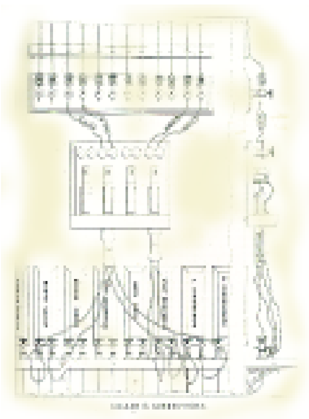


Figure 6
The switchboard of the Harvard College Observatory, first installed in 1859, was basically an internal telegraph system used as what today would be called a local-area data network. The arrangement, here of the upgraded system installed in 1871, shows the switchboard from both the top (most of the picture) and the side (far right). Six pairs of wires (top) could be connected through four switches (middle plate) to link any combination of three instruments (bottom); the connections shown make a circuit between the west equatorial (a refracting telescope of four-inch aperture and 60-inch focal length) with the south clock and the east chronograph. Moreover, financed by the U.S. Coast Survey, the switchboard allowed for temporary electrical connections to link Harvard College Observatory to telegraph wires around the country for geodetic operations. The system could also *transmit* time signals to regulate timepieces.

[*Annals of the Harvard College Observatory*, (Cambridge: Metcalf & Co., 1856) vol. VIII, part I, p. Plate IV (opposite page 22)]

which "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"—essentially precluded getting clear skies at both places the same night.[7] Thus, the transit telescopes at both ends of the cables were used primarily to nail down local times.

In addition, because of the weak voltages over nearly 2,000 miles of cable, no fillet register could automatically record the signals. Instead, the astronomers at each end had to eyeball 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. In short, only clock signals were exchanged by eye and hand—a striking parallel to Wilkes' pioneering first experiment in comparing chronometers by eye and ear 22 years earlier.

From October 24 through November 20, 1866, clock signals were exchanged on five nights. Experiments on other nights quantified the observers' personal equations and determined the velocity of the signals over such an unprecedented length of wire. 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 the Greenwich Observatory and from Heart's Content to the U.S. Naval Observatory.

By this experiment, the telegraph yielded the first directly-measured longitude of the dome of the U.S. Capitol west of the Greenwich Observatory: five hours, eight minutes, and 2.22 seconds.

That was the good news. The bad news was that the signaling method used essentially turned the cable into a giant capacitor, whose discharge rate affected the signal transmission times. And so this transatlantic measurement, while the first word, was not yet the last.

WIDER INFLUENCE

As ambiguous as the first transatlantic determination of longitude by the American method was, by 1866 the telegraph had bequeathed far more to astronomy and geodesy than precise longitude measurements.

Perhaps its greatest contribution was the "American method of transits," widely adopted at individual observatories in the United States and abroad for nightly astronomical data recording [Fig. 6].[8] Astronomers quickly realized the telegraph allowed them to use not just the customary seven widely-spaced vertical wires in a transit telescope's

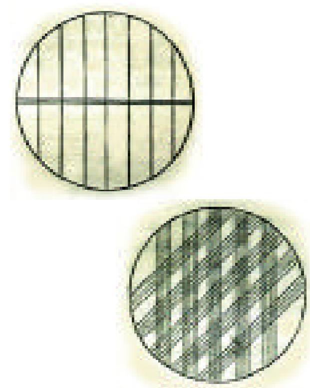


Figure 7
The telegraph literally influenced telescope—specifically eyepiece—design. With the "American method of transits" system, an astronomer tapped a telegraph key each instant a star crossed a vertical wire in his telescope, instead of listening to clock ticks and counting seconds and calculating the delay of looking at a clock face before manually writing down the time. Because an astronomer could tap a telegraph key as rapidly as a piano key, he or she could keep eye glued to eyepiece and could make timings every second or two instead of needing 10 or 15 seconds between wires. Thus, instead of being restricted to the five or seven vertical wires standard in transit telescope eyepieces of the 1840s (upper), wires could be more closely spaced. As a result, 19th-century astronomers made eyepieces with 35 or more wires—including special-purpose ones with wires at an angle (lower) for measuring differences in declination (celestial latitude) as well as right ascension (celestial longitude) for star catalogues.

[Elias Loomis, *An Introduction to Practical Astronomy* (New York: Harper & Bros., 5th edition, 1863), pp. 52 and 93] field of view, but to install dozens of finely-spaced wires, eliminating the need for multiple nights of observation to attain the same precision [Fig. 7]. In other words, the telegraph as electromagnetic observing assistant increased the precision and productivity of astronomical timings—according to contemporary estimates—by a factor between 4 and 60, meaning observers could produce star catalogues much faster. Moreover, by taking over timekeeping and recording functions, the telegraph effectively "de-skilled" astronomical timings—meaning that positional astronomy now could be farmed out to relatively inexperienced observers.

The telegraph and chronograph also sparked astronomers' discussions on quantifying personal equation and reaction time,[9] techniques that ultimately made their way into instrumental psychology. Lastly, the telegraph provided steady income to astronomical observatories from selling accurate local time signals—and later standard time signals—to railroads and jewelers; by the late 19th century, such time services had paved the way for the acceptance of standard time zones worldwide.[10]

REFERENCES

1. *Dava Sobel's Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time* (Walker Publishing Co., New York, 1995) 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* (Walker Publishing Co., New York, 1998) covers the right 19th-century time period, but focuses exclusively on the telegraph as a traditional communications medium, omitting all uses of what we would now call "data communications."

2. 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).

3. A contemporary summary of Wilkes observations plus other important early results appears in Section IV "Application of the Electric Telegraph to Astronomical Uses" of Chapter IV of *The Recent Progress of Astronomy; Especially in the United States* (New York: Harper & Brothers, third edition, 1856) by Elias Loomis, one of the astronomical pioneers of the American method.

4. 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.) *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 its first two directors, Ferdinand Rudolph Hassler and Alexander Dallas Bache.

5. Sears C. Walker, "Telegraphic Operations of the Coast Survey.—Velocity of the Galvanic wave," *American Journal of Science*, series 2, volume 8, 1849, p. 143.

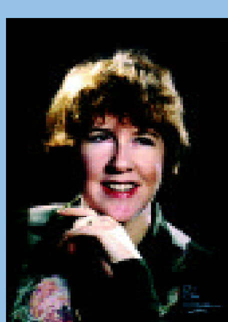
6. Airy, George B., "On the Method of observing and recording Transits, lately introduced in America; and on some other connected subjects," Monthly Notices of the Royal Astronomical Society, vol. 10, p. 26, 1849. I am indebted to Professor Rand Evans, department of psychology, East Carolina University, for pointing out the connection to the name "American method."

7. The story of the first telegraphic determination of transatlantic longitude was detailed by Benjamin Apthorp Gould in "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.

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

9. Simon Schaffer, "Astronomers Mark Time: Discipline and the Personal Equation," *Science in Context*, vol. 2 (1988): 115-45.

10. For a definitive history of the role of the telegraph in time services and time balls operated by 19th-century observatories, see Ian Bartky's *Selling the True Time: Nineteenth-Century Timekeeping in America* (Stanford University Press, 2000). See also O'Malley, op. cit.



Trudy E. Bell, an independent scholar and freelance science and technology journalist, has a master's degree in the history of science and American intellectual history from New York University in 1978. Formerly an editor for *Scientific American* magazine (1971-78) and a senior editor for *IEEE Spectrum* magazine (1983-97), she is the author of some 300 articles on astronomy, history of astronomy, engineering, scientific expeditions, and science and adventure travel—17 of which have won top journalism awards. She was the lead writer for the IEEE's millennium book *Engineering Tomorrow: Today's Technology Experts Envision the Next Century* (IEEE Press, 2000—see *www.ieee.org/products/tomorrow/*) and is working on an oral-history book for the IEEE Microwave Theory and Techniques Society on the history of radio and radar since World War II (see *http://206.166.222.61/MTT.pdf*).
(*t.e.bell@ieee.org* and *http://home.att.net/~trudy.bell*)