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Nineteenth-century longitude determinations in the Great Lakes region: government-university collaborations

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Abstract
The longitude problem – determining geographic position with precision on land or at sea – was one of the greatest scientific problems of all time. Yet, this fascinating history was virtually forgotten until 1993 when William J H Andrewes at Harvard University organized an international symposium and Dava Sobel wrote her best-selling book *Longitude* (1995). But, this recent attention stopped short of chronicling the important contributions made by nineteenth-century astronomical observatories in determining the longitude across America. University observatories collaborated on longitude determinations with government agencies such as the United States Lake Survey to enable them to perform accurate surveys of land and coastal areas. This research provides the historical context of nineteenth-century longitude determinations in America. Specific examples and details are drawn from Great Lakes longitude determinations performed through collaborations between the U. S. Lake Survey and academic astronomers at the Hudson Observatory at Western Reserve College, Harvard College Observatory, Hamilton College Observatory, and the University of Michigan Detroit Observatory.

Key words: *longitude, telegraph, United States Lake Survey, United States Coast Survey, Detroit Observatory*

1 INTRODUCTION

In 1993, Harvard University hosted an international symposium on longitude, which was attended by 500 people from seventeen countries (Andrewes, 1996). This event refocused attention on one of the greatest scientific challenges of all time – the longitude problem. It also prompted Dava Sobel to write her *New York Times* best-selling book, *Longitude* (1995), which makes accessible to the layperson the fascinating history of the longitude problem in all its scientific detail.

In the concluding remarks at the Harvard symposium, one of the speakers provided a stunning demonstration of the advancement of scientific technology over the last 150 years. He pulled out a pocket-sized Global Positioning System (GPS) instrument, and after the push of a button, announced the exact latitude and longitude of the position he occupied at the podium. It was not always this easy. The longitude problem challenged the most eminent scientists from the very beginnings of navigation at sea until the 1870s, by which time longitude was as easily determined as latitude, facilitated by the electric telegraph, the chronograph, and other scientific advancements.

By the twentieth century, the history of the longitude problem had become obscure. The Harvard symposium placed the longitude problem once again in the international spotlight, but it stopped short of chronicling the important contributions made by nineteenth-century astronomical observatories in determining longitude across America. It was nineteenth-century longitude determinations that permitted accurate surveys of land and coastal areas.

The discovery by the author in 1996 of 164 chronograph data sheets at the University of Michigan, spanning the years 1860-1901, provided invaluable primary source material and triggered a great curiosity that led to this in-depth examination of nineteenth-century longitude determinations in the Great Lakes region (Figure 1). The chronograph data sheets contain meridian circle telescope observations and clock signals recorded at the University of Michigan Detroit Observatory,[1] located in Ann Arbor. The collection appears to be complete, beginning with the earliest chronograph data sheets created in 1860 when the University of Michigan purchased its first chronograph, and ending in 1901, at which point the chronograph likely become antiquated, falling out of use.

Figure 1. Great Lakes Region circa 1823 by F Lucas, Jr., Baltimore, Maryland, B T Welch, engraver (Courtesy: William L. Clements Library, University of Michigan).

This research presents the historical context of nineteenth-century longitude determinations, and the specific details of Great Lakes longitude determinations made between 1858 and 1869 by the United States Lake Survey in collaboration with academic observatories. University and college participation included the observatories at Western Reserve College in Hudson, Ohio; Hamilton College in Clinton, New York; Harvard College in Cambridge, Massachusetts; and the University of Michigan in Ann Arbor.

2 THE LONGITUDE PROBLEM

The British Parliament established a prize in 1714 of £20,000, to be awarded to the person who could solve the longitude problem. Longitude and latitude are the critical co-ordinates of descriptive geography, which are needed to determine position on land or at sea. Longitude became a great concern to England and other European countries that relied on ships to transport people and goods, because without an accurate means of determining longitude at sea, many vessels went off course and experienced costly delays or were tragically lost. Determination of latitude was easily performed using a sextant or other instrument to measure the angle between the horizon and the Sun or the pole star, thereby establishing the ship's distance from the equator. Determination of longitude, however, was a far greater challenge.

It was expected that an astronomer would solve the longitude problem, largely because astronomical science was employed for related determinations, such as latitude. But, it was actually a clock-maker named John Harrison who was the successful contestant, although he struggled for decades before his invention received the recognition it deserved. Harrison developed a marine timekeeper, a very reliable clock capable of maintaining an accurate rate at sea by its ability to compensate for the pitch and roll of the ship, dramatic changes in temperature and humidity, and other challenging environmental conditions that other clocks could not withstand. Although Harrison spent 40 years obsessing and doing battle to have his invention officially recognized, his fourth marine timekeeper, which he completed in 1759, was eventually awarded the coveted prize. Harrison's precise timekeeper led to the development of the marine chronometer, which revolutionized navigation around the globe.

3 A NATIONAL OBSERVATORY

Astronomy was considered to be the science of the elite in the early decades of Colonial America. Many prominent men, and some women, owned telescopes and pursued astronomy primarily as a hobby. President John Quincy Adams' interest in astronomy manifested itself as a personal resolve to remove the control of time from nature, as determined by the sundial and the almanac, and place it under the control of educated scientists and the government. But, his idea was ridiculed, and his phrase "light-houses of the skies" was used to mock his efforts to establish a national observatory, because the United States Coast Survey was the priority in the 1820s. The uncharted US shoreline was treacherous, claiming many vessels, lives, and valuable goods. A comprehensive survey of the coast was needed to provide accurate charts for safe navigation.

Yet, Adams continued to press for a national observatory. He cautioned against reliance on European observatories, which numbered in excess of 130, and said "... are we not cutting ourselves off from the means of returning light for light, while we have neither observatory nor observer upon our half of the globe, and the earth revolves in perpetual darkness to our unsearching eyes?" (Jones and Boyd, 1971:36). In Adams' view, "There is not one study in the whole circle of the sciences more useful to the race of man upon earth, or more suited to the dignity of his destination as a being endowed with reason, and born to immortality, than the science of the stars... The history of Astronomy has been, in all ages, the history of Genius and Industry, in their blazing light and untiring toil, patronized by power." (*Centenary of the Cincinnati Observatory*, 1944:27).

Nearly two decades passed before Adams' vision for a national observatory was achieved. Small steps helped to clear the way for progress. One early step was the creation of a small astronomical observatory known as the dépôt of charts and instruments. The dépôt was quietly set up by Lieutenant Charles Wilkes of the Coast Survey near Capitol Hill in Washington in the early 1830s, and used primarily to rate chronometers for the Navy's fleet of ships. Astronomy had, therein, gained a higher national priority because of its utility to the Coast Survey.

West Point Observatory was established in 1839, and the following year, Sears C Walker opened the Philadelphia High School Observatory. In 1843, Ormsby M Mitchel opened the Cincinnati Observatory. At Mitchel's invitation, John Quincy

Adams, despite his advancing age and fragile health, made the long journey to Cincinnati to lay the cornerstone at the building's dedication. He would not miss this opportunity to celebrate the "... perseverance to accomplish what [he had] promised." (*Centenary of the Cincinnati Observatory*, 1944:20). Finally, in 1844, a National (Naval) Observatory was established at Washington, just four years before Adams died. Academic observatories began to appear, as well, including Williams College (1836), Western Reserve College (1838), and Harvard College (1839).

4 THE UNITED STATES COAST SURVEY

By 1847, the United States Coast Survey reported in the astronomical journal *Sidereal Messenger* that it had achieved resounding success:

> Within the last five years, a complete revolution has taken place in our country. The great experiment of inducing the people generally, to contribute for the erection and support of institutions devoted to pure science, has been successfully tried, and the results have attracted the notice, and secured the high commendation of foreigners, who once believed such results impossible. (Mitchel, 1848:55).

Prior to the creation of the Coast Survey, charts of the shores and harbours of North America were undertaken by J F W Des Barres, His Majesty's Surveyor-General for the Colonies. Then in 1806, Ferdinand R Hassler proposed a complete navigational survey based upon a uniform system. Hassler, a native of Switzerland who had studied geodesy under the most eminent European scientists, began his career in Switzerland with the triangulation of the Canton of Berne. This prepared him well for his appointment by Thomas Jefferson in 1807 as the inaugural Superintendent of the Coast Survey. Hassler's charge was to chart the nation's coasts and its land formations for the safe navigation of ships. At that time, on average, three hundred vessels were annually wrecked along the Atlantic Coast (The Coast Survey, 1879:520). If a ship captain's determination of longitude was off by even one second, this was significant: at the equator, one degree of longitude is equivalent to about 111 kilometres (exactly 60 nautical miles), so, one second of longitude is equal to about 1.85 kilometres (exactly 1 nautical mile). Over the course of a lengthy transatlantic passage, a ship could find itself seriously off course. Navigation and surveying required great precision.

Unfortunately, the War of 1812 and other factors caused a lapse in the Coast Survey's surveying efforts. The Coast Survey work recommenced in 1832. During the period of neglect, the distinguished civilian hydrographers, Edmund W Blunt and his son, of New York, provided information to ensure the safe navigation of ships (Loomis, 1879:507).[2] Civilians continued to make observations for the government after the Coast Survey was fully operational. William Mitchell and "his assistant," (who was, no doubt, his daughter, Maria Mitchell, who now figures prominently in the history of astronomy), made important observations of Moon culminations and meridian transits at Nantucket, Massachusetts (Davis, 1851:11). From 1832 onward, the Coast Survey was active in making contributions to science, including studies of magnetism and sea currents. Ferdinand Hassler died in 1843 and was succeeded by Alexander Dallas Bache, a great grandson of Benjamin Franklin and nephew of Vice President of the United States Alexander Dallas.

Explorations of the South Seas were launched in 1838, led by Lieutenant Wilkes. These explorations refocused attention on the utility of astronomical observations. The heavens co-operated, too, by captivating public attention with spectacular displays of meteor showers and awesome comets – their long tails blazing across the sky. Comets were heralded by the educated as opportunities to expand knowledge, but some were superstitious that comets might be "... forerunner(s) of pestilence, famine, or some other dreadful calamity." (Watson, 1861:vii). Gradually, astronomy became more accessible by the general public, and with this change, came a wider acceptance of astronomical science (Bruce, 1987:101).

5 LAND SURVEYS

Knowledge of astronomy was brought to America by the first explorers, because astronomical methods were essential to navigation. Astronomical methods also had utility to the early surveyors. The burgeoning emigrant population prompted territories to initiate public surveys so that the land could be sold. In the Michigan Territory, a public survey began in 1815.

Cartographers and surveyors needed accurate co-ordinates to create geographical and navigational maps, yet no reliable means existed to accurately determine the longitude. In recognition of the problem, Congress adopted in 1785 the Governmental Land Surveys' system of dividing land, called the "Rectangular System." Following this plan, an arbitrary line was established in the Michigan Territory in 1815 to serve as the principal meridian line. It extended due north from the mouth of the Auglaize River, a branch of the Maumee River in Ohio, to St. Mary's Falls at the northern point in the Upper Peninsula. A baseline was also established, located to intersect the meridian line along the northern boundary of Wayne County, running due west across the Michigan Territory as the northern boundary of a line of other counties, across to Lake Michigan (Figure 2). These co-ordinates served as the points of reference for all future triangulation surveys of Michigan. Comparable meridian lines and baselines were established for other states and territories.

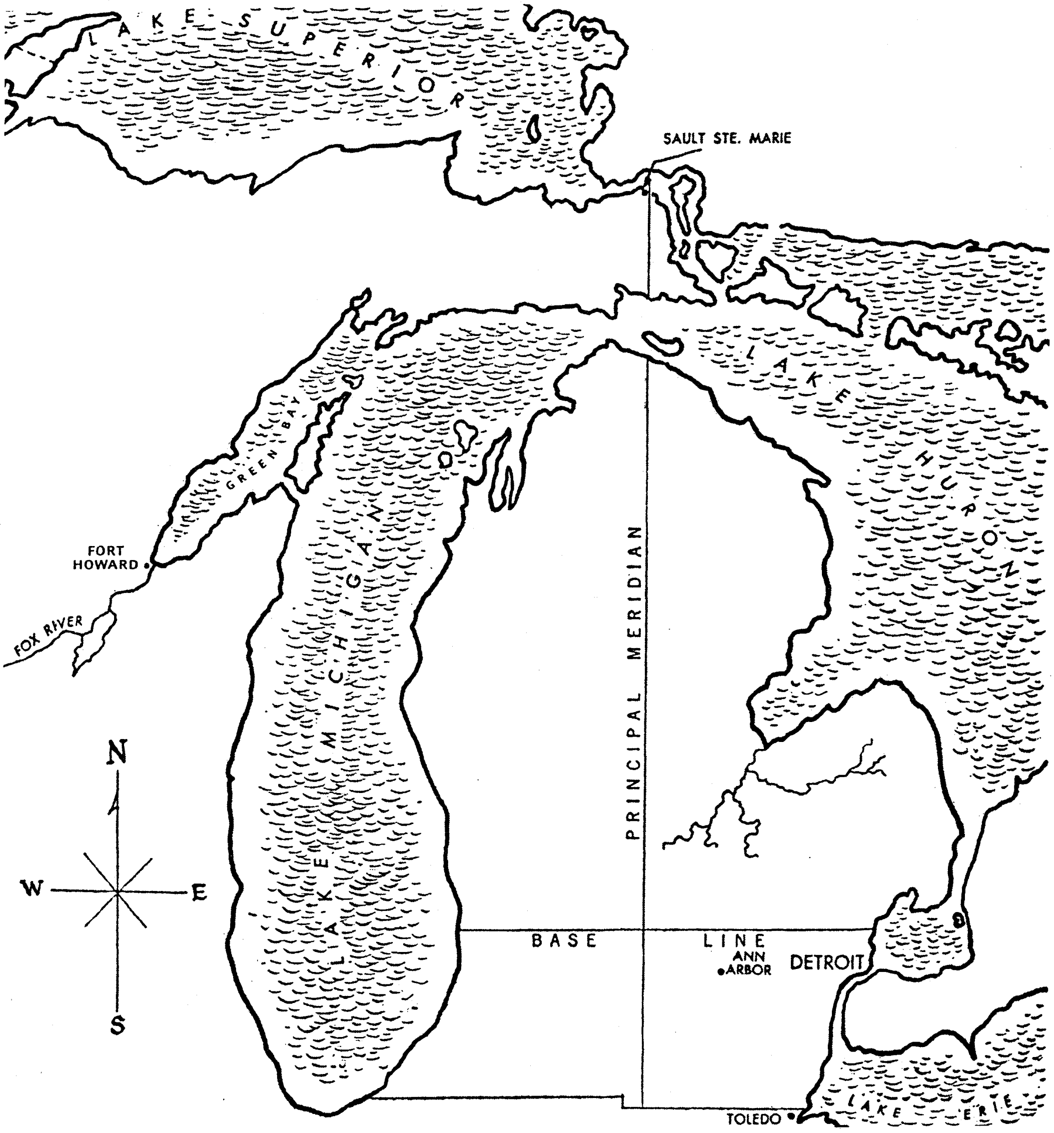


Figure 2. Baseline and meridian line established for Michigan in 1815 (adapted from Bald, 1954:152).

As railroads and canals were established across the United States, and the land became settled, the need for accurate land surveys became more critical. Precision land surveying was very important to railroads in acquiring land to lay down track. Without proper surveys, property disputes could subsequently arise, with serious consequences if tracks had to be moved. When the need arose to string wires across the country for the electric telegraph, the clear stretches along railway beds served admirably.

Early surveys were often grossly inaccurate, in some cases misrepresenting the position of cities by 4.8 kilometres (3 miles) or more, owing to the imperfection of the instruments used, the presence of iron deposits that interfered with compass readings, and the "... ignorance, carelessness and dishonesty ..." of some surveyors (Farmer, 1901:302). The solar compass (Figure 3), which was invented by William Austin Burt[3] of Michigan (see Burt, 1844), was patented on 1835 February 25. It helped to alleviate the interference of iron ore deposits on the accuracy of the compass needle. The solar compass, through the ingenious use of the Sun's rays to determine the exact position of a north-south line, made it possible to conduct accurate surveys in areas where the presence of minerals made the conventional compass useless. Geologist Bela Hubbard said of his use of the solar compass for surveys of Michigan's Upper Peninsula in 1845:

> This accuracy has been attained by the exclusive use, by all the parties, of "Burt's Solar Compass," an instrument too well known to need more than a bare allusion, but the great value of which has been more than fully confirmed during the surveys of the past season.... It seems difficult to imagine how the lands could have been run with the ordinary compass. (Burt, 1985:70).

Sir John Herschel commended the invention in 1851 after it had been perfected the previous year. The solar compass was also recognized in 1851 with a medal from the Franklin Institute and a prize medal at the Great Exposition at the Crystal Palace in London.

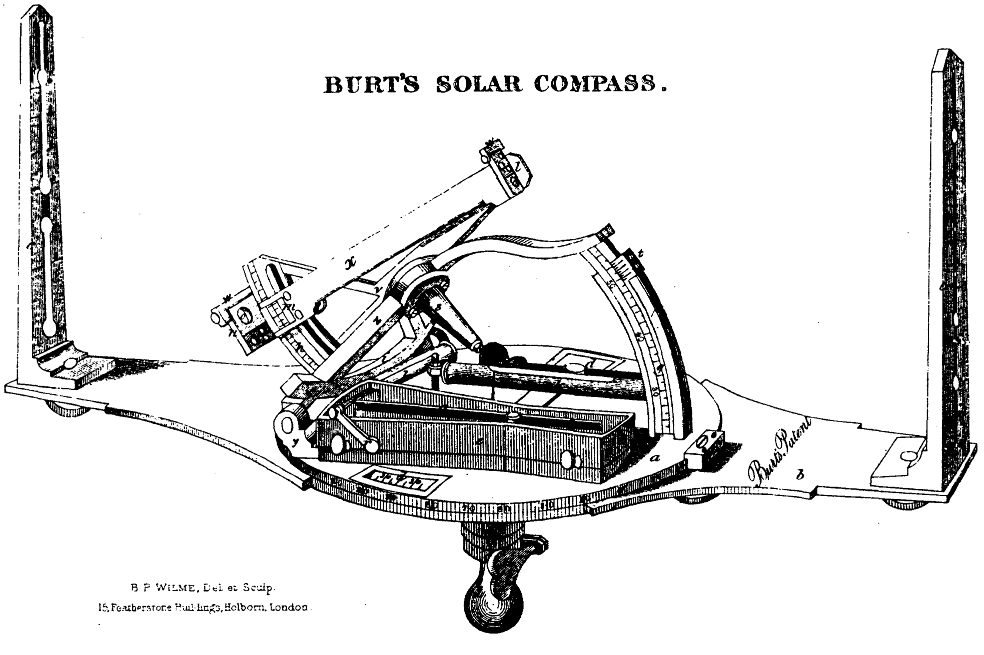


Figure 3. Burt's solar compass was invented in Michigan in 1835 (after Tuttle, 1873:517).

Even with the benefit of the solar compass, surveying work was exceptionally difficult and dangerous, pushing men to the limits of their endurance. In 1847, with a solar compass in hand, Henry Wiltse, a U.S. Topographical Engineer, led his surveying party through the Lake Superior territory in Wisconsin. He later recounted the details of the challenges and privation:

> ... the men were 'packed' with the utmost limit of their strength, and yet each member of the party was restricted to the clothes upon his back, and a single blanket, that they might be able to carry the greatest amount of provision, which was made to consist of pork and flour alone.... During four successive weeks there was not a dry garment in the party, day or night. The work was done in the long hot days of June and July. Consider a situation like the above, connected with the dreadful swamps through which we waded, and the great extent of windfalls [trees prostrated by the wind] over which we clambered; the deep and rapid creeks and rivers that we crossed, all at their highest stage of water; that we were constantly surrounded, and as constantly excoriated by swarms, or rather clouds of musquitoes [sic.], and other still more troublesome insects; and, consider further, that we were all the while confined to a line, and, consequently, had no choice of ground; that we were forced to follow that line wherever and through whatever it chanced to carry us, and you can form some idea of our peculiar, if not suffering, situation. (State Historical Society of Wisconsin, **IV**:1859:362).

It was important to get the job done correctly the first time, because neither man nor beast would willingly volunteer to repeat such an arduous ordeal.

6 LONGITUDE DETERMINATIONS IN AMERICA BEFORE THE TELEGAPH

The establishment of baselines and meridian lines made it possible to conduct land surveys by triangulation, but the use of arbitrary lines held limited value in the absence of accurate longitude. Prior to the electric telegraph, explorers, cartographers and agencies such as the United States Coast Survey and United States Lake Survey employed various astronomical methods to determine longitude, even though they recognized that the methods were imprecise. Methods of determining longitude included observations of eclipses of Jupiter's satellites, instantaneous signals, celestial phenomena, and lunar distances.

6.1 Jupiter's Satellites

Longitude could be determined in the field and at sea by observing eclipses of Jupiter's satellites. The time of the exact instant of disappearance and reappearance of each satellite could be checked against an ephemeris to calculate the difference between local time and the Greenwich time provided in the ephemeris. Complicated mathematical reductions were also needed. This method required clear skies, the proper equipment, and a significant investment of time, the combination of which was difficult for early explorers to achieve in the field. Even with the best equipment and conditions, the method was imprecise. Eclipses of Jupiter's satellites were an uncertain measure due to the considerable size of the satellites and their tendency to disappear and reappear gradually rather than instantaneously.

Meriwether Lewis, for the 1803 Lewis and Clark expedition through the Louisiana Territory to the Pacific Coast, carried the best chronometer available at the time. But, timekeepers were not yet sufficiently reliable, and the rigours, the elements, and the temperature extremes to which Lewis' chronometer was subjected during his journey rendered the timepiece inadequate for precision longitude determinations. Ships at sea typically carried several chronometers for comparative purposes, the time of which they regularly checked using astronomical instruments. In contrast, Lewis was able to carry only one timepiece and portable astronomical equipment, and there was little time for extensive observations and complicated mathematical reductions.

6.2 Instantaneous Signals

Several experimental means were used in the early nineteenth century to determine distances and positions by sending instantaneous signals. In 1843, as part of the Canadian survey of the Bay of Fundy, under the direction of Captain H W Bayfield of the British Royal Navy, rockets were detonated to determine times and positions. The ship *Columbia* in Bedford Basin set off rockets that were observed by the *Gulinare* in Halifax Harbour, a distance of 40 kilometres (25 miles) (Thomson, 1966:189). The United States Lake Survey used rockets and also employed "powder-flashing" in longitude work done at Lake Superior. The flash from ignited gunpowder could be observed from a distance of about 18 kilometres (30 miles) (Comstock, 1882:28). Signals were given from distance intervals of about 1.2 kilometres (2 miles) by means of a "delicate wand" or flag during daylight hours (Davis, 1851:11). Sunlight reflected off a small mirror, or heliotrope,[4] could be seen at distances up to 280 kilometres (175 miles) under the right conditions. Interestingly, mirrors were also used to telegraph messages using Morse code signals (Comstock, 1882:18). Morse code signals were also exchanged between ships within 0.3 kilometres (½ mile) of one another (Maver, 1904). One ship struck a hammer against a bell positioned below water level, while a second ship received the signal by listening through an ear piece attached to a trumpet-shaped tube that extended below the water (Figure 4). At night, a lamp was used to project a beam of light through a perforated board, which was visible at a considerable distance (Davis, 1879:514, 520). The various instantaneous signals used in establishing distances and positions were thought to provide a high degree of accuracy, though their utility was limited to short distances.

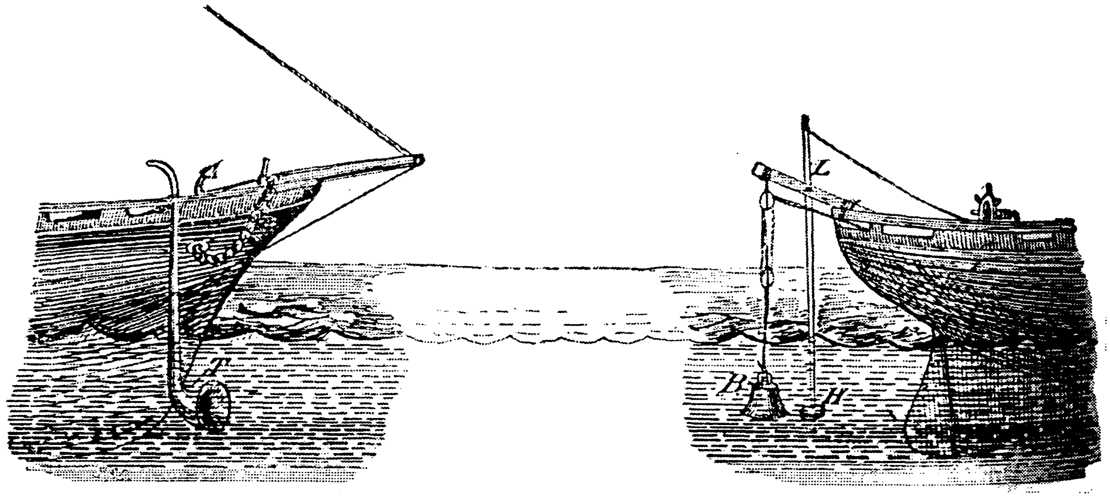


Figure 4. Ships communicated by sending Morse code signals underwater. Sound was produced by the stroke of a hammer (*H*) against a bell (*B*) and received by ear through a trumpet (*T*) which was placed below the water line (after Maver, 1904:286).

6.3 Celestial Phenomena

Longitude determinations were sometimes performed through observation of instantaneous celestial phenomena such as shooting stars or bursting meteors; solar and lunar eclipses; and occultations of the stars and planets by the Moon. Such phenomena were visible at the same absolute moment by observers positioned anywhere across the globe, although the local time of observation varied by location. Each hour of difference in local time corresponded to a 15-degree difference in longitude. But, these observational methods held flaws. Meteor events were difficult to identify at remote stations. Solar and lunar eclipse observations tended to be inaccurate due to the imperfect definition of Earth's shadow. And, occultations of stars and planets by the Moon were troublesome because the Moon's parallax is not absolute for all observers – it can vary depending upon the observer's location. These methods required numerous, repeated observations in order to reduce the amount of error (Chauvenet, 1891, I:314-420; Loomis, 1879:305-343; Olmstead, 1854:124).

6.4 Method of Lunar Distances

The method of lunar distances served for several centuries as the most reliable means of measuring longitude. The method was first introduced in 1514 by Johann Werner of Nuremberg, and was refined over subsequent centuries. Longitude and time are rooted together with Earth's rotation on its axis, so that the difference in longitude between two positions can be found by comparing the local time of these two points. Timepieces were not accurate enough on land nor at sea to serve reliably in longitude determinations. Werner and others observed that the Moon's motion serves as a sort of clock, with the Moon being the hand of the clock and the Sun, stars and planets being the markers on the dial. In the course of a year, as Earth revolves around the Sun and the Moon around Earth, the angular distance between the Moon and selected stars varies with the passage of time. Furthermore, the angular distance between the Moon and the Sun varies in the course of a lunar month, as the Moon progresses through its phases. These factors make the changing lunar distance a useful measure of time. Yet, what appears to be simple in principle is mathematically complex. The calculations must make allowance for atmospheric refraction and for lunar parallax, because observations are made from Earth's surface rather than from Earth's centre. Further, the accuracy needed for longitude measurements requires an instrument of great precision, an accurate star catalogue, and accurate predictions several years in advance of the motion of the Sun, Moon, and stars. Publication of an annual ephemeris (almanac) based on the Greenwich meridian, which commenced in 1767, simplified the process of deducing Greenwich time (Howse 1996:150-161; Chauvenet, 1891, I:393-395). The method of lunar distances gradually fell out of use as chronometers became more accurate on land and at sea.

7 CAMBRIDGE, MASSACHUSETTS: 'THE AMERICAN GREENWICH'

By the early 1840s, several observatories were established in America. The Harvard College Observatory, established in 1839, was located in Cambridge, Massachusetts, and was often referred in the USA to during the nineteenth-century as the 'Cambridge Observatory'. It was situated close to Boston's shipping port, which was convenient for chronometric expeditions between American and England. William C Bond, director of the Harvard College Observatory, had an office for his chronometer business, Wm. Bond & Son, located near Boston harbour, from which he established a direct telegraph connection to the Harvard observatory clock. This telegraph connection eliminated the need to transport chronometers overland from Boston harbour to the observatory at Cambridge, thus avoiding any possibility of error the journey might have introduced (Gould, 1869:3).

As early as 1845, the Harvard College Observatory was regarded as "... the best determined position in America ..." from which the longitude of all other principal positions in the United States was determined (Bailey, 1931:104). Over the course of many years, Bond determined the longitude of his Observatory through repeated observations of eclipses, transits, occultations, and Moon culminations. His longitude was recognized in 1845 for its reliability by the American and British Commissions leading the Survey of the Northeastern Boundary. Bond's longitude determinations proved so accurate that only slight modifications were later needed to correct for data obtained on subsequent chronometer expeditions, and from eventual telegraph and radio longitude determinations.

During the summer of 1849, the longitude of Harvard College Observatory was repeatedly checked using chronometers carried aboard ships that crossed the Atlantic Ocean between England and Boston. Initially, chronometers carried aboard the Cunard line of steamers were utilized for this purpose (Davis, 1851:27). When this commercial means was determined to have reached the limits of its accuracy, chronometers were specially prepared and rated by Bond for the purpose of determining the longitude.

Bond's chronometric expeditions culminated in 1855 with six transatlantic voyages carrying as many as fifty-two chronometers together aboard ship between Cambridge, Massachusetts and Liverpool under the care of Sydney Coolidge, a volunteer assistant at the Harvard College Observatory (Gould, 1869:5; Bailey, 1931:51). Coolidge also made the requisite transit observations both at Cambridge and Liverpool. Coolidge, who was the grandson of Thomas Jefferson, served the Harvard College Observatory without pay from 1853 until 1860, at which time he joined the Civil War effort.[5] The mean rate of the clocks Coolidge transported from Europe was used to check the distance between Cambridge, Massachusetts and the Liverpool observatory, the longitude of which from Greenwich was precisely known. It was this rigorous series of voyages between England and Boston that earned international confidence in Bond's longitude.

Cambridge thus became the zero-point of longitude on the American continent. The longitude of locations in America was thereafter determined based upon the longitude of Cambridge, Massachusetts, which came to be considered the 'Greenwich of America'. Longitude was expressed in terms of distance west from Greenwich, or west from Cambridge, to which was added the distance between Cambridge and Greenwich. Gradually, observatories across the United States determined their distance from Cambridge, thereby establishing their longitude.

By the early 1850s, longitude determinations of fixed points extended from the Atlantic Coast to the eastern outskirts of the Midwest. Longitude was established between Cambridge and New York (1848), Philadelphia (1849), and Washington (1849). In 1849, the Philadelphia High School Observatory and the Hudson Observatory at Western Reserve College in Hudson, Ohio, collaborated to determine longitudes, a venture that established the first accurate co-ordinates from which territorial and local surveys of the mid-western United States could be referenced. The observatory at Seaton Station, located at Washington, collaborated on the longitude with Savannah, Georgia, in 1851, and with Roslyn Station, near Petersburgh, Virginia, and Charleston, South Carolina, in 1852. Seaton Station and Savannah then connected with the observatory at Amherst College in Massachusetts in 1850 and 1851 respectively. About the same time, a connection established between Washington and the Cincinnati Observatory served as an important step in determining the distance between Washington and New Orleans (André and Angot, 1877:31; Davis, 1851:27; Loomis, 1874; Loomis, 1879:310; Nourse, 1874). These established points of longitude were, over time, linked to other observatories across the country, with the chain eventually extending all the way from the Atlantic Coast to San Francisco. These reference points for longitude were critical elements in the accuracy of North American maps and charts.

8 THE ELECTRIC TELEGRAPH AND CHRONOGRAPH

The conception by Samuel F B Morse of the electric telegraph in 1832 proved to revolutionize the determination of longitude by eliminating much of the error inherent in existing methods. Morse made his first demonstration of the electric telegraph in 1835 at the University of the City of New York, where he was on the faculty. Fellow faculty member, Henry P Tappan, who became the first president of the University of Michigan in 1852, witnessed Morse's practical demonstration of the telegraph with a small group of others.

Controversy over the identity of *the* true inventor was commonplace during this era of scientific discovery, and Morse's discovery was not exempt; his invention of the electric telegraph was hotly disputed. Testimonials were the principal basis for the settlement of such controversies. In 1868, Morse called upon Tappan to write a letter verifying what he had observed regarding Morse's invention. On 1868 February 14, Tappan wrote to his wife while he was away in Berlin to share a transcript of his letter in support of Morse. His letter captures his excitement about scientific discovery, and his thrill in being associated with the men responsible for great inventions:

> It is curious that the painter Fulton should be father of Steam Navigation, and indeed also of Railroads, for the propulsion of vessels on water led to the propulsion of locomotives on land, by steam: and the painter Morse the father of the Electro-magnetic Telegraph. What a change these two inventions have made in the world! How they have carried forward the centuries! And they both owe their inventions to American painters! (Tappan, 1868).

Morse was eventually successful in his lengthy succession of lawsuits, receiving a large fortune in royalties. His invention of the electric telegraph revolutionized the entire world to a degree comparable to the invention of the printing press 400 years earlier (Dibner 1964:1).

The electric telegraph made it possible to connect clocks at observatories located a considerable distance apart. The clocks could then be compared, taking into account the transmission time of a signal over the telegraph wire – the fraction of a second it took the current to pass over the distance between one station and another. The electric telegraph method, when combined with the use of an electric chronograph, made it possible to record with great precision the timing of star transits. Although credit for the invention of the chronograph is debated, between John Locke of Cincinnati, Ohio, and William C Bond of Harvard College Observatory, it was Bond who greatly improved the instrument. His invention of the 'spring-governor' employed a pendulum and a flywheel to ensure uniformity in the revolution of the cylinder (Bailey 1927:38-39). For this invention, Bond was awarded a gold medal at the Crystal Palace Exposition in London in 1851.

The chronograph consisted of a brass cylinder covered with paper, and a pen electrically controlled by a galvanic battery (Figure 5). The cylinder rotated by means of weight-driven clockwork at the rate of one revolution per sidereal minute. Each sheet could record up to two hours of work. Electrical wires were utilized to connect the chronograph to an astronomical clock. Each swing of the clock's pendulum broke the electric current, thereby jogging the pen to record the seconds on the paper in exact

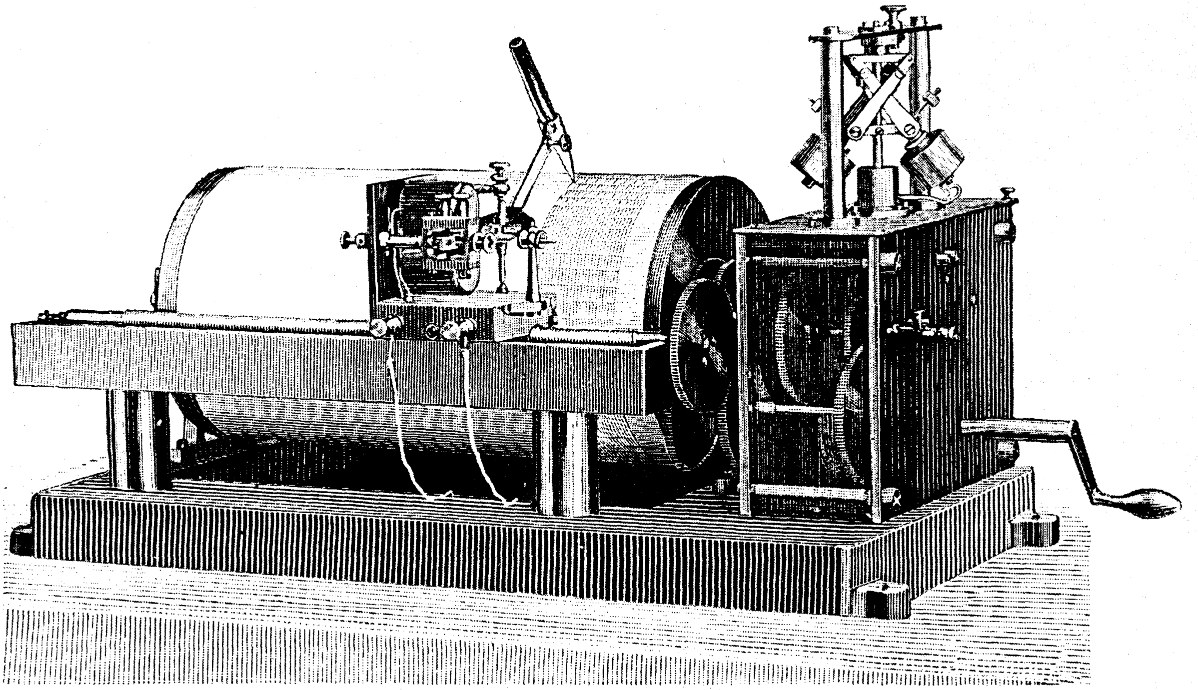


Figure 5. Electric chronograph showing the pen in the process of inscribing data on paper attached to the revolving drum (after Ambronn, 1899:1049).

coincidence with the beats of the clock. The observer, looking through a meridian circle telescope, recorded the transit of a star by pressing a key at the exact instant the star crossed the various wires in the reticle of the meridian circle's eyepiece (see Figure 6). In this way, the precise timing of the passage of a star could be ascertained.

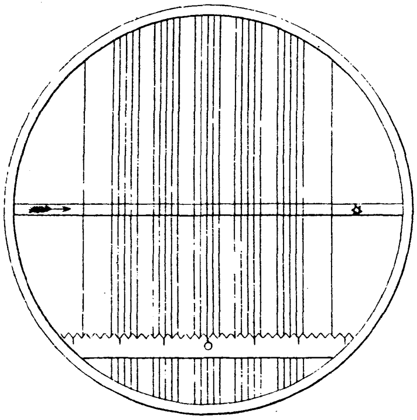


Figure 6. Reticle of a meridian circle telescope showing spider lines, or wires, and micrometer (after Chauvenet, 1891, II:Plate 1, Figure 1).

By comparing data recorded on the chronographs, the distance between two observatories could be determined. If the longitude of one observatory was already known, the longitude of the other could be calculated by determining the distance between it and the known longitude. Sears C Walker of the United States Coast Survey originally suggested this method of determining longitude, utilizing star signals and a chronograph attached to a galvanic circuit to record astronomical observations (Chauvenet, 1891, I:342). The method's growing reputation for great accuracy caught the attention of Alexander Dallas Bache, Superintendent of the Coast Survey, who soon called the chronographic method into use. Walker's method came to be known as the 'American method'. Observers at two stations a distance east and west of each other noted the meridian passage of stars and recorded the time of transit using the clock at the eastern most station. Data from the recorded times of transit were reduced to determine the equivalent distance, thereby arriving at the distance between stations.

Even though Walker's American method of determining longitude had been in use for a decade, in 1858 Captain George C Meade, who had charge of the United States Lake Survey from 1857 to 1861, suggested a change to C A Young of the Hudson Observatory at Western Reserve College in Hudson, Ohio. Young found Meade's modification to be innovative, and the results virtually free of error. Instead of utilizing only one clock at the eastern most observatory to record the time of a star's transit, Meade suggested that two clocks be utilized, one at each observatory (Meade, 1913:211-212).

The electric telegraph was used extensively within Europe to determine the longitude of various locations. In the United States, connections were made between the Harvard College Observatory and other nearby observatories, because the Harvard College Observatory had already determined its distance from the prime meridian at Greenwich. Gradually, connections between observatories were made, from the East Coast to the South, and to the Midwest. An automatic repeater was introduced around 1860, which enabled transmission of telegraph signals beyond the previous limit of about 480 kilometres (300 miles) (Coe, 1993:78-79). The following year, a transcontinental telegraph line was completed, permitting telegraph communication from the Atlantic all the way to the Pacific Coast. As the telegraph stretched across the country, longitude determinations followed shortly behind, by way of St. Louis, Missouri, and Salt Lake City, Utah, to San Francisco, California.

9 THE ATLANTIC CABLE

Another great technological challenge of the mid-nineteenth century was to connect Europe and America by telegraph. Telegraph lines were omnipresent across the United States and Europe. Yet, bodies of water continued to present obstacles to communication. In 1842, Morse devised a means of laying telegraph lines underwater. He spanned New York harbour using a copper wire insulated with hemp soaked in tar pitch and coated with indiarubber (Bright, 1903:16). Ezra Cornell got involved three years later when he laid a cable across the Hudson River to connect Fort Lee with New York. This early technology did not withstand the harsh conditions to which it was subjected, such as ice floes in winter. Experiments with different materials, such as gutta-percha, and various construction techniques were ongoing. The prototypes of the cable grew stronger with each improvement that was introduced.

The great momentum of the spread of telegraphic technology brought with it a widespread desire for international communication. It became clear that a transatlantic telegraph cable was needed. It would be a monumental undertaking. Interest in a transatlantic cable was extensive, and nineteenth-century ambition seemed to have no boundaries. Beyond the utility of determining the longitude, a submarine cable across the Atlantic would connect the continents for personal and business communications, effectively reducing communication time by weeks. In thinking about a transatlantic telegraph cable, there were many unknowns. Would an electric signal travel over such a great distance, and at such depth? What was the terrain of the ocean bed? No soundings had yet been taken of the ocean floor, and the ability to lay a submarine cable depended entirely on the terrain. Perhaps the most challenging question of all was, how would such an undertaking be financed?

New Yorkers Cyrus W Field and Peter Cooper stepped forward to provide the leadership and financial backing that, with the assistance of many others, carried the project forward. World geography determined the route, extending over land and sea from New York to Newfoundland, and across the ocean to Valentia, Ireland. Successful submarine telegraph lines had already been run in Europe across the English Channel in 1851, and between Corsica and La Spezia, Italy, in 1854. Then, on 1857 July 16, the first telegraphic cable was laid across the Detroit River in Michigan. To achieve the durability needed for such a feat, a cable identical to the Atlantic cable prototype was obtained (Figure 7). The Detroit River cable was considered by some to be "... the first really successful submarine telegraph cable laid in any waters." (Farmer, 1884:884-885). These early prototypes helped to guide the refinement of the submarine cable, the construction of which was improved as deficiencies were noted in testing.

The process of laying the Atlantic cable was fraught with problems and setbacks. The first expedition in 1857, and a subsequent attempt in 1858, both failed. But, a

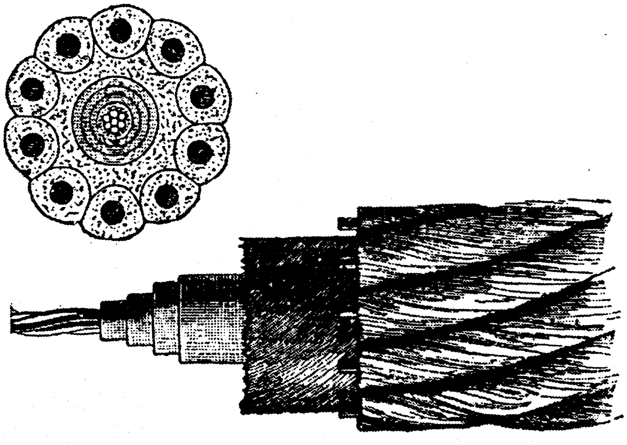


Figure 7. Anatomy of the Atlantic Cable (after Bright, 1903:52)

second attempt in 1858 met with success in August of that year. The nation rejoiced, and Field's hometown, New York City, was the centre of jubilation. Franz Brünnow, director of the Detroit Observatory at the University of Michigan, wrote to George P Bond at the Harvard College Observatory:

> ... as the Atlantic Telegraph is an established fact now, I suppose the Cambridge observatory [Harvard College Observatory] will be the first to make use of it for a more accurate determination of the longitude, if it should ever work well enough for that purpose. (Brünnow, 1858).

Brünnow's scepticism was prescient, because in October, the telegraph signal became weak, and then faded completely. An investigation determined that high voltages had ruined the cable. This was a major disaster, but Field and others were undaunted. Only 732 messages had been communicated over the Atlantic telegraph in 1858 (Abbott, 1934:96), but the great utility of these communications motivated Field and others to make another attempt. The next five years were spent in the total reconstruction of the plans. Field was convinced he could make it work, but in 1865, another attempt failed when the cable broke.

The year before, a separate plan was put into motion to explore the possibility of an overland telegraph that would connect America with Europe by way of San Francisco and the Yukon Territory (known then as Russian America). By this route, the underwater portion of the telegraph cable, across Bering Strait from the Yukon Territory to Russia, would be a distance of only about 65 kilometres (40 miles). The Western Union Telegraph Company provided the capital for the project, and the Smithsonian Institution was called upon to identify a leader for an exploratory mission. Robert Kennicott, an explorer and naturalist from Chicago, was recruited. He had already explored the remote regions of Hudson Bay, and was well prepared for the "... hardship, privation, and isolation." of arctic journeys (Dall, 1895:123), but died during the mission. Other scientists, such as William H Dall, Mark W Harrington, and Marcus Baker,[6] carried on the work, including Kennicott's natural features inventory and collection of animal, plant, and geological specimens.

In 1866 September, there was great jubilation when the two lost ends of the 1865 Atlantic cable were recovered and successfully spliced. The Atlantic Cable was finally complete! Many distinguished officials attended a banquet in Cyrus Field's honour to recognize this great achievement. Congress granted Field a gold medal for his dedication and persistence over the nearly thirteen years of the project. When word of the success of the Atlantic Cable reached Alaska in late 1867 July, the Alaskan telegraph expedition was abandoned. But, the Alaska expedition had generated great interest in the region, and this was one of several factors that influenced the American government to purchase the Alaska territory.

10 UNITED STATES LAKE SURVEY

The idea to undertake a survey of the Great Lakes region was first suggested in 1831 at a meeting held in Detroit, Michigan, but ten years passed before the United States Lake Survey was created in 1841 by act of Congress. The Lake Survey's mission was to prepare charts and take soundings of the north and north-western lakes. Explorers and fur traders had identified a wealth of natural resources in the interior regions of this territory, such as iron ore, coal, limestone, lumber, copper, and other products. The Great Lakes were the principal means of accessing the interior of the continent, but in order to safely enter these waters, navigators needed a reliable source of accurate charts (Unites States Lake Survey, 1939). Accurate charts would enable commerce to proceed in safety.

After a few years at Buffalo, New York, the Lake Survey office relocated in 1845 to Detroit in a building at the corner of Wayne and Congress Streets (Farmer, 1884:918; United States Lake Survey, 1939:1-2, 34). In 1857, Detroit merchant John Hull made available to the Lake Survey at no cost a vacant lot on Washington Avenue near Grand River Avenue. No doubt, Hull found the arrangement advantageous to his business because he alone provided the supplies needed for the Lake Survey's lengthy surveying excursions. A wooden building was erected on this site and equipped for astronomical and magnetic observations (Comstock, 1882:11). Then, in 1865, the Lake Survey relocated to permanent headquarters in Detroit at the junction of Grand River Avenue and Park Place.

Parties of surveyors, up to 200 men in number, were deployed at Detroit from May through October. They had two steamers at their disposal to take soundings of the lakes from the shore to a point 16 kilometres (10 miles) out. The data they collected were used to ascertain the depth of the lakes, and to note any obstructions such as reefs and shoals. Rowboats were used to explore the shoreline, and shore parties travelled inland to survey the terrain. Teams of three men used triangulation methods to determine the accurate location of prominent objects and places on land. During the winter months, data were computed and transcribed for publication, and charts were drafted and engraved. By 1883, the Coast Survey annually sold 6,400 charts (Farmer, 1884:918).

Captain Meade, who had charge of the Lake Survey from 1857 to 1861, was a gifted scientist. His abilities were so admired by Joseph Henry, Secretary of the Smithsonian Institution, that Henry tried to dissuade Meade from taking a military leadership position during the Civil War, fearing that Meade's considerable scientific talents would be lost to the war effort. Henry's pleas were unsuccessful in retaining Meade in his scientific capacity. As history reveals, Meade left the Lake Survey in 1861 when called to duty by General McClellan, whereupon he took command of a reserves group in Pennsylvania. In 1863, he became a national hero by winning the Battle of Gettysburg.

11 GREAT LAKES LONGITUDE DETERMINATIONS

Between 1858 and 1869, numerous university observatories collaborated with the United States Lake Survey on longitude determinations in the Great Lakes region, including the observatories at Harvard College, Western Reserve College, Hamilton College, and the University of Michigan. These invaluable collaborations greatly contributed to the accuracy of navigational charts, maps, and land surveys of the Great Lakes region.

11.1 Sand Point, Saginaw Bay, Michigan, 1858

Captain Meade of the Lake Survey collaborated with academic astronomers in 1858 on the determination of the longitude of Sand Point at Saginaw Bay, Michigan. Topographical engineer Lieutenant Turnbull and assistant James Carr collected observational data of the Moon and Moon culminating stars, and these data were then sent by Meade to George P Bond at the Harvard College Observatory to perform the complicated mathematical reductions (Meade, 1858:4).

11.2 Ann Arbor, Michigan, 1858

It was in 1858 March that the longitude of Ann Arbor, Michigan, was first determined, by Franz F E Brünnow (Figure 8), the director of the University of Michigan's Detroit Observatory, from occultations of the *Pleiades* (Brünnow, 1861:17). Brünnow reported in the scholarly journal he created and edited, *Astronomical Notices*, that he determined the longitude of Ann Arbor to be $26^h\ 4^m\ 0^s$ west from Washington. This was done with the assistance of George P Bond, who provided observations made on 1858 March 19 of occultations of the *Pleiades* (Brünnow, 1861:1).

Henry P Tappan, the University of Michigan's first president, recruited Brünnow from Berlin in 1854 to be the inaugural director of Tappan's new observatory.

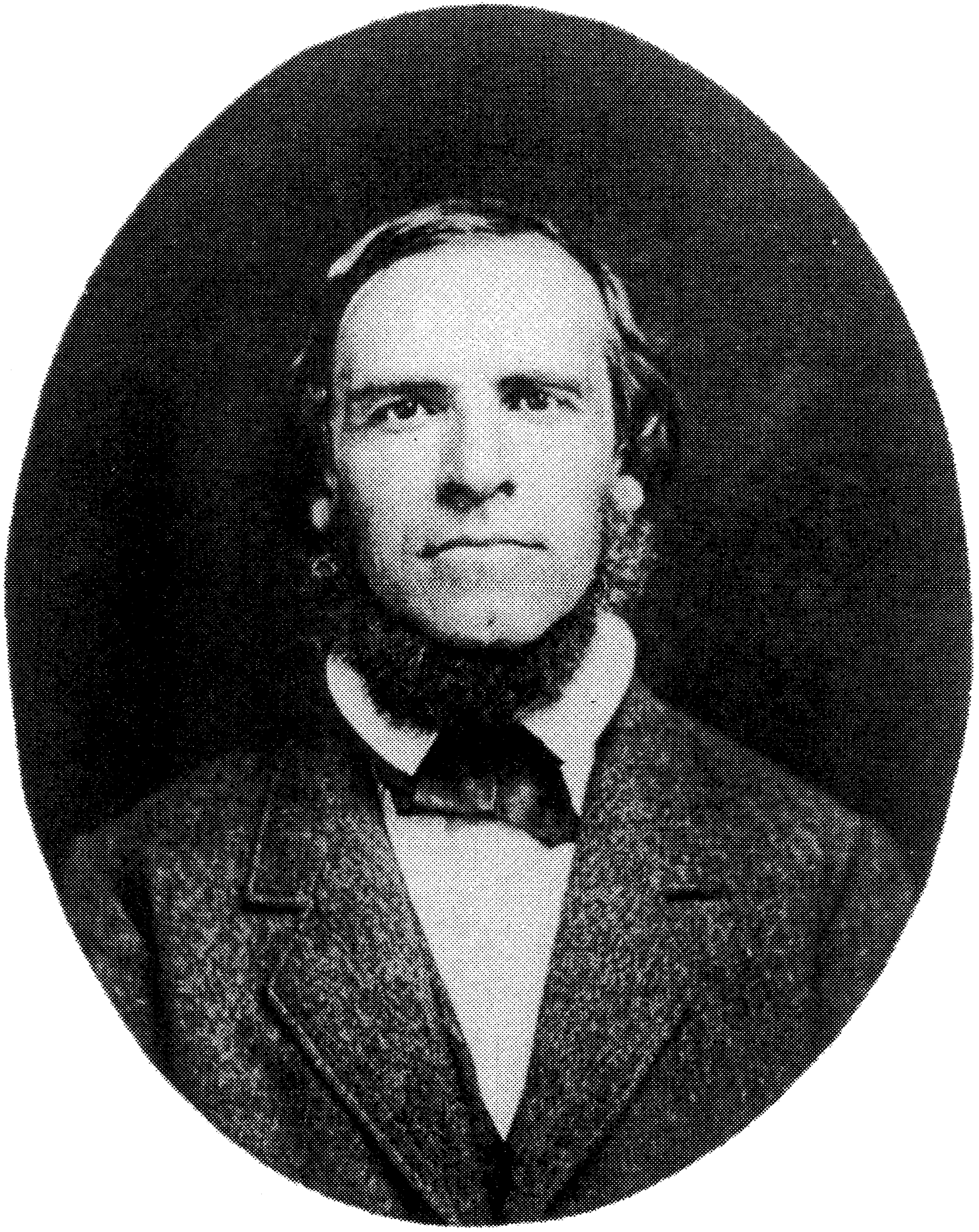


Figure 8. Franz F E Brünnow (1821-1891), inaugural Director of the University of Michigan Detroit Observatory, 1854-1864 (Courtesy: Bentley Historical Library, University of Michigan).

Brünnow was the favorite student and acclaimed assistant of the renowned astronomer Johann Encke of the Berlin Observatory. While in Berlin, Tappan asked Brünnow to inspect the 6-inch meridian circle telescope (Figure 9) he had ordered from the firm of Pistor & Martins of Berlin and also the astronomical clock ordered from M Tiede of Berlin, before they were shipped to America. Brünnow had greatly admired the meridian circle, and it later occurred to Tappan that the astronomer might wish to follow the telescope to America.

11.3 Hudson, Ohio ↔ Detroit, Michigan, 1858

Shortly after Meade's appointment as head of the Lake Survey, he was eager to determine the longitude of the Lake Survey's base of operations at Detroit by means of the telegraphic method, because of the method's proven accuracy. To achieve this, he needed to collaborate with an observatory whose longitude was well established by the telegraphic method. Meade desired to undertake this work in 1857, but the instruments required for the observations did not arrive in time. In 1858, with the new instruments in place, he was ready. The closest observatory with a well-established longitude determined by the telegraphic method was the Hudson Observatory at Western Reserve College in Hudson, Ohio. Astronomer Elias Loomis, who founded the Hudson Observatory in 1838, established its longitude in 1849 by telegraphic connection with Philadelphia.

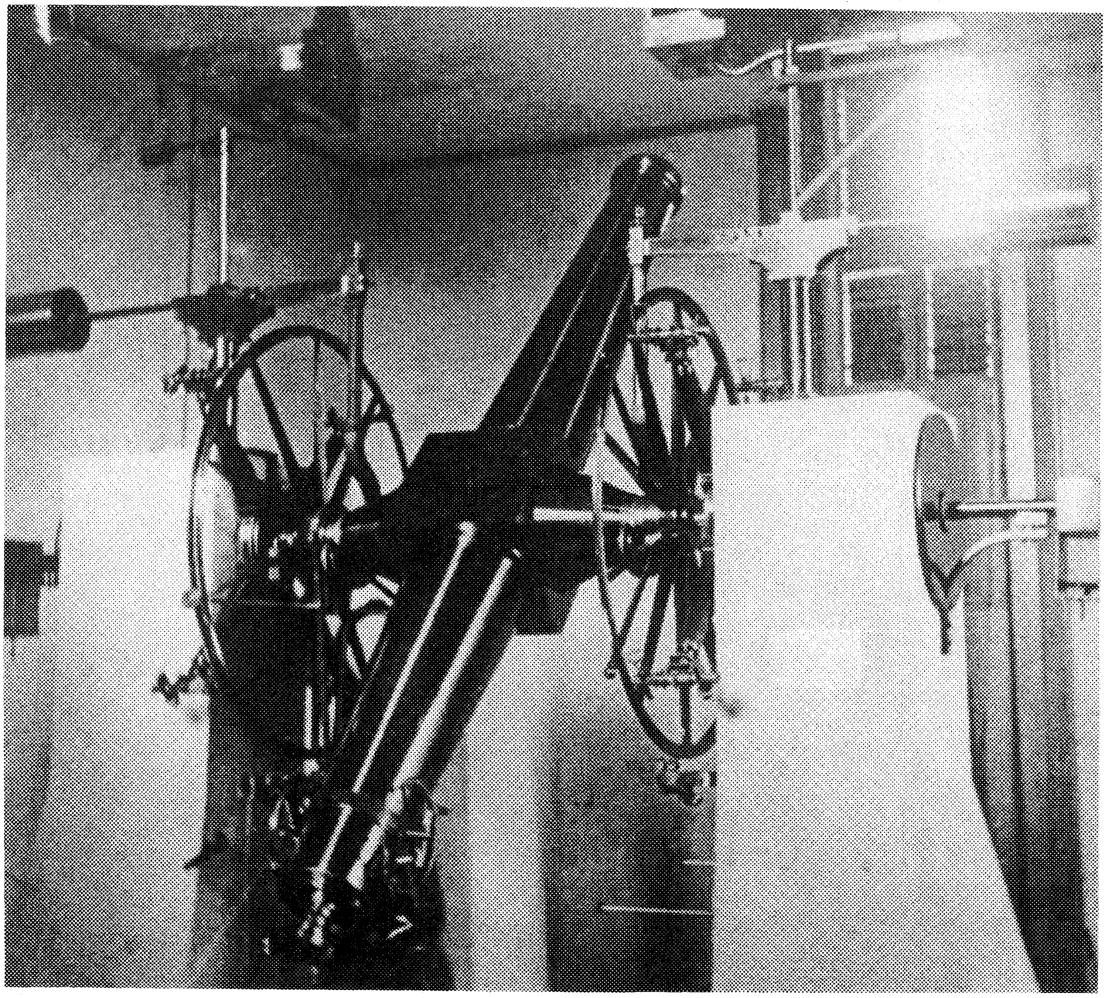


Figure 9. Meridian circle telescope at the University of Michigan Detroit Observatory, made in 1854 by Pistor & Martins of Berlin. Astronomical clock by M Tiede of Berlin is mounted on the limestone clock pier (behind the left circle) (Courtesy: Bentley Historical Library, University of Michigan).

In preparation for the 1858 longitude determination between Hudson, Ohio and Detroit, an arrangement was made with Anson Stager of the Western Telegraph Company for free, uninterrupted use of the telegraph wire after 9 p.m., when it was less busy. Turnbull, the observer in Detroit, recorded his observations using a chronograph, and C A Young at Western Reserve College used a Morse register.[7] The transits of particular stars and their local times were recorded at both stations, and the longitude of Detroit was then determined from reductions of these data. To complete the process, Turnbull easily determined the latitude of Detroit through a series of observations over seven evenings in 1859 April and May using a zenith telescope (Comstock, 1882:11). Meade thus obtained the first accurate determinations of longitude and latitude for Detroit, which would be invaluable to him in establishing survey triangulations in the Great Lakes region.

11.4 Ann Arbor, Michigan ↔ Detroit, Michigan, 1860

In 1860 May, Lieutenant O M Poe of the Lake Survey contacted James C Watson (see Figure 10), Brünnow's assistant at the University of Michigan Detroit Observatory, who had charge of the Observatory during Brünnow's one-year absence as Associate Director of the Dudley Observatory in Albany, New York. Poe desired to check the accuracy of the longitude of the Lake Survey observatory at Detroit, and Watson agreed to help. The method used by Watson and Poe was an exchange of arbitrary signals over the telegraph wire – a method less accurate than use of an electric telegraph and a chronograph. Yet, it was the only method available to Watson in 1860, because the University of Michigan did not yet have a chronograph as part of its astronomical equipment, nor was there a direct telegraph connection to the Detroit Observatory at Ann Arbor.

On the evening of 1860 May 26, Watson was ready as darkness approached. Notebook in hand, he wrote "The weather having cleared up just before dark the following observations were made with the meridian circle." (University of Michigan

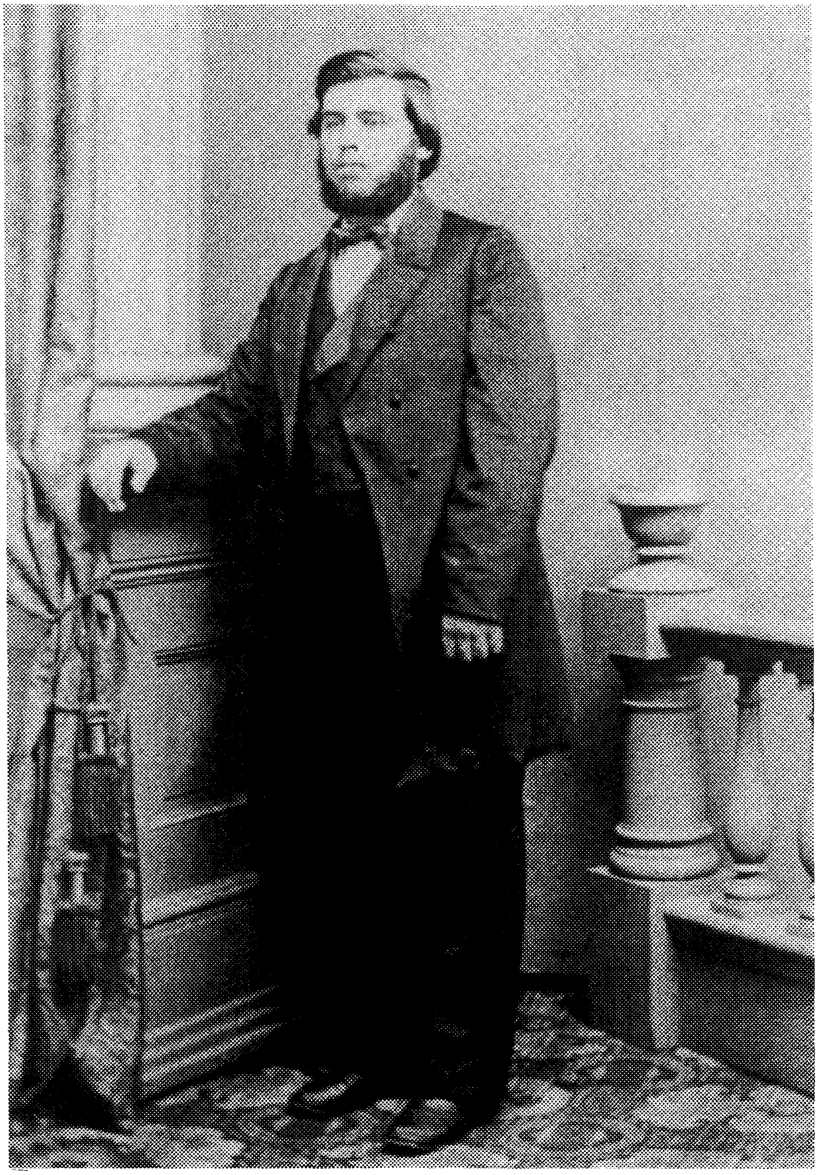


Figure 10. James C Watson (1838-1880), educated at the University of Michigan Detroit Observatory, and director from 1864-1879 (Courtesy: Bentley Historical Library, University of Michigan).

Observatory Records, Box 12). The temperature was 18.4°C (65°F) outside and 19.5°C (67°F) inside the east wing of the Observatory, which held an 1854 Pistor & Martins meridian circle telescope. The barometric pressure registered 97.826 kilopascals (28.888 inches of mercury).

Beginning at 11:38:35.5 p.m., Watson made observations of the stars Leonis, Ursae Majoris, and Virginis, noting the time of transit over the wires of the meridian circle telescope's reticle. He recorded the following in his logbook:

Leonis
$11^h\ 38^m\ 35^s.5$
49.4
3.4
17.7
32.0
45.8
11 39 59.7

Ursae Majoris
$11^h\ 45^m\ 13^s.6$ }
37.3 } last three wires
11 46 0.5 }

Virginis
$12^h\ 9^m\ 26^s.5$
39.8
53.4
10 7.2
20.8
34.4
12 10 47.8

He then checked the alignment of the meridian circle telescope using the spirit level, with the telescope's clamp set at the East.

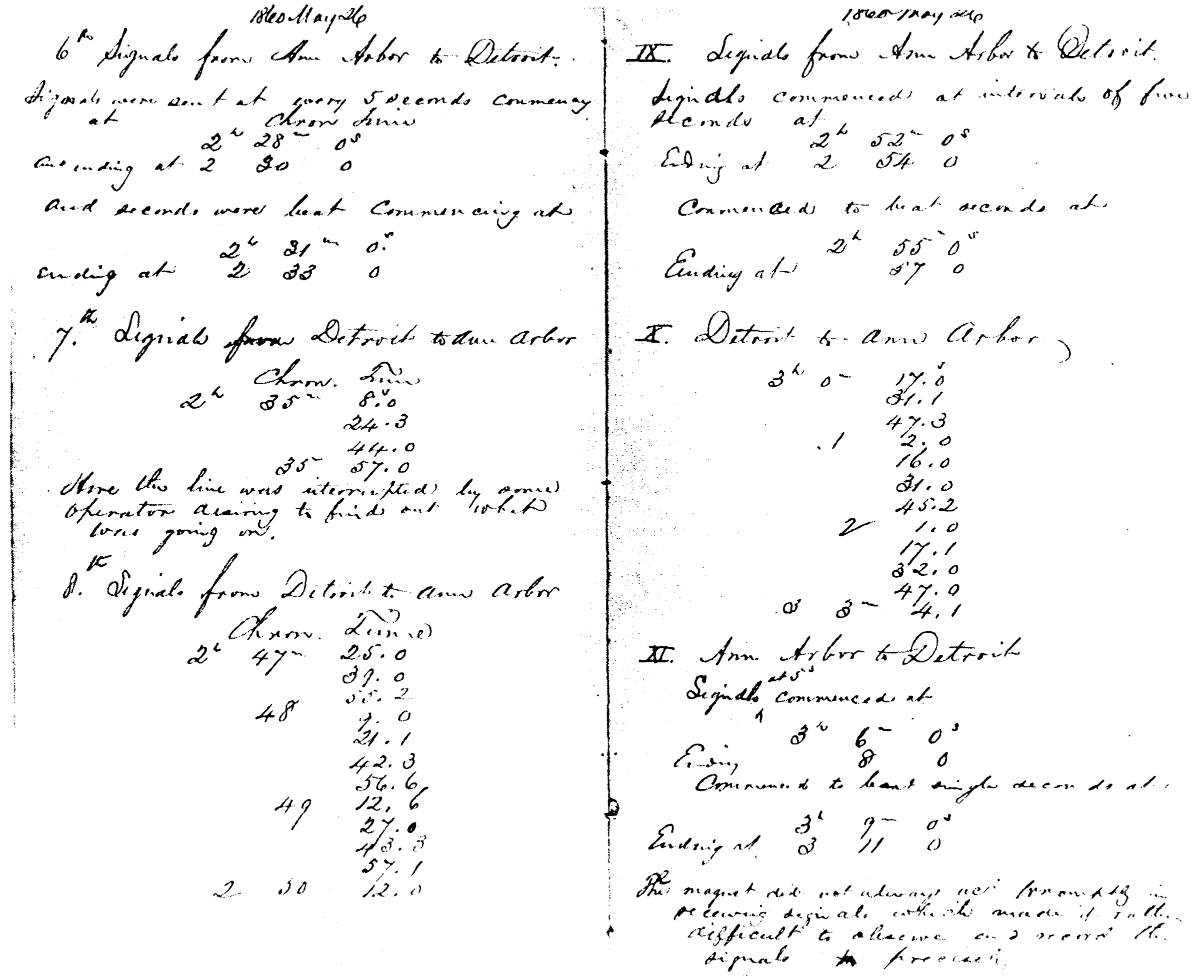
Next, Watson determined the correct local time using data from his observations. He found that his chronometer was 9 minutes 36.5 seconds fast compared with the Observatory's clock, and he recorded this in his notebook for later use in making his reductions. He then transported the chronometer on foot with great care to the local telegraph office, which was situated at the Michigan Central Railway depot, just 0.4 kilometres (¼ mile) north-west of the Observatory. There, he received signals by telegraph from Poe in Detroit. Signals were exchanged back and forth fifteen times in all. Watson tapped out the time at intervals of five seconds for one minute, then every second for the final minute.

During the second transmission of signals from Detroit, Watson noted that "Here the line was interrupted by some [telegraph] operator desiring to find out what was going on." (see Figure 11) (University of Michigan Observatory Records, Box 12). The odd repetitions of tapping out the seconds would certainly have seemed out of the ordinary to a telegraph operator accustomed to hearing Morse code signals. The interruption caused a few minutes delay, but Poe and Watson were able to complete the exchange of signals at 3:38 a.m., whereupon Watson returned to the Observatory with his chronometer in hand. He arrived back at the Observatory at 4:10 a.m. and immediately compared the chronometer with the Observatory clock. The error was 0.7 seconds, which he noted in his logbook.

Unfortunately, the Lake Survey's efforts in working with Watson to determine the longitude were not rewarded. Meade of the Lake Survey found that the results were not "... entirely satisfactory ..." (Comstock, 1882:11), and Tappan later revealed the true nature of the problem:

2000JAHH....3..131W

> Mr. Watson had entire charge of the Observatory, during Dr. Brünnow's absence of one year in Albany. Nothing was accomplished at the Observatory during this year. And in the spring, when the Lake Survey made signals of the time to him, by telegraph, for the purpose of determining the longitude, he failed to make the requisite observations for the correction of his time, and they were compelled to wait some two or three weeks for the reductions. (Tappan, 1915:1145).



1860 May 26

6th Signals from Ann Arbor to Detroit.

Signals were sent at every 5 seconds commencing at
Chron Time
$2^h\ 28^m\ 0^s$
and ending at 2 30 0

And seconds were beat commencing at
$2^h\ 31^m\ 0^s$
ending at 2 33 0

7th Signals ~~from~~ Detroit to Ann Arbor
Chron. Time
$2^h\ 35^m\ 8.0^s$
24.3
44.0
35 57.0
Here the line was interrupted by some operator desiring to find out what was going on.

8th Signals from Detroit to Ann Arbor
Chron. Time
$2^h\ 47^m$ 25.0
39.0
55.2
48 9.0
21.1
42.3
56.6
49 12.6
27.0
43.3
57.1
2 50 12.0

1860 May 26

IX. Signals from Ann Arbor to Detroit.
Signals commenced at intervals of five seconds at
$2^h\ 52^m\ 0^s$
Ending at 2 54 0

Commenced to beat seconds at
$2^h\ 55^m\ 0^s$
Ending at 57 0

X. Detroit to Ann Arbor
$3^h\ 0^m\ 17.0^s$
31.1
47.3
1 2.0
16.0
31.0
45.2
2 1.0
17.1
32.0
47.0
3 3 4.1

XI. Ann Arbor to Detroit
Signals at 5s commenced at
$3^h\ 6^m\ 0^s$
Ending 8 0
Commenced to beat single seconds at
$3^h\ 9^m\ 0^s$
Ending at 3 11 0

The magnet did not always act promptly in receiving signals which made it rather difficult to observe and record the signals [illegible] precisely.

Figure 11. Page from James C Watson's logbook dated 1860 May 26 showing his notes from an attempt to determine the longitude of Detroit (Courtesy: Bentley Historical Library, University of Michigan).

11.5 Ann Arbor, Michigan ↔ Detroit, Michigan, 1861

When Brünnow resigned from the Dudley Observatory in 1860 to return to his director position in Ann Arbor, he obtained approval from the University of Michigan Board of Regents to purchase a chronograph, made by Wm. Bond & Son. The chronograph was shipped to Ann Arbor, but was delayed in transit. Brünnow wrote to George P Bond in October that "The chronograph has not arrived yet probably on account of the crowded state of the [Erie] Canal." (Brünnow, 1860a). It finally reached Ann Arbor in November.

Brünnow learned a great deal about the processes involved in timekeeping and determination of longitude during the year he spent at the Dudley Observatory. He participated in putting a time service into operation in Albany, and he worked in co-operation with the Harvard College Observatory in 1860 to determine the longitude of the Dudley Observatory (Brünnow, 1860b). Upon his return to Ann Arbor later that year, he also pursued the establishment of a time service in Michigan, enlisting the assistance of George Bond's father, William C Bond, director of Harvard College

Observatory. The Bonds provided the time for the City of Boston, so when the citizens of Detroit asked Brünnow to investigate the feasibility of establishing a time service for Detroit, he naturally sought guidance from the Bonds. Once the Ann Arbor time service was in place,[8] the time was telegraphed from Ann Arbor to Detroit and other cities in the region. Jeweller Martin S Smith displayed the time on a large clock mounted outside his store in downtown Detroit, by which passers-by could set their timepieces. Ships in the Detroit harbour could set their chronometers by a time ball mounted atop Smith's building (Figure 12), which was dropped daily at precisely noon.

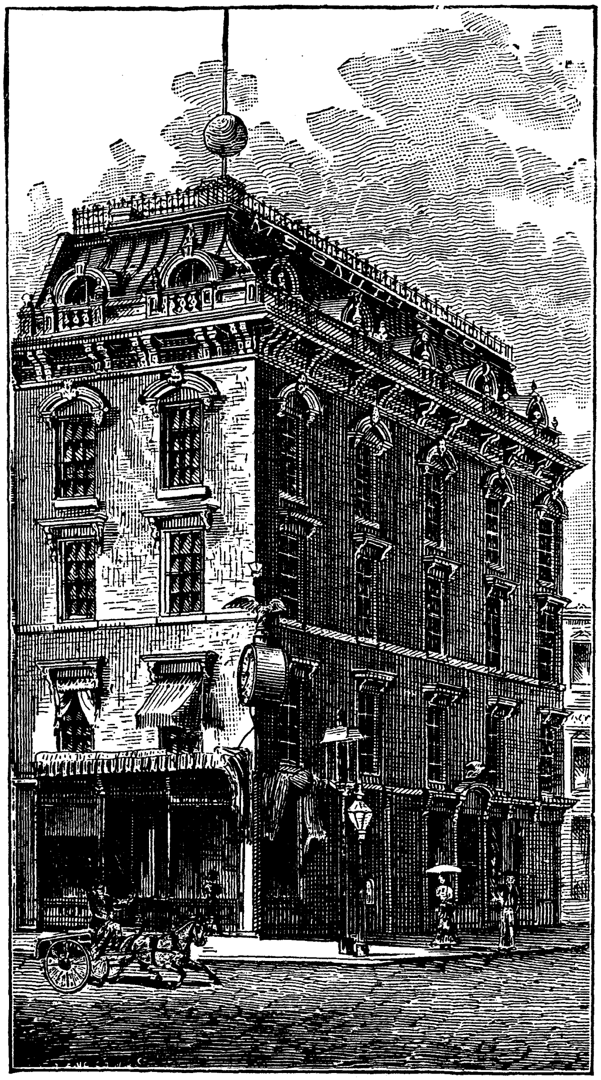


Figure 12. Time provided by the University of Michigan Detroit Observatory was communicated to the city of Detroit using a time ball and clock at Smith's Jewelry Store (after Farmer, 1884:363)

It was the installation of a telegraph line that connected the Detroit Observatory with the nearby Michigan Central Railroad depot, and possession of a chronograph, that made it possible for Brünnow to collaborate with the United States Lake Survey to determine longitude by the telegraphic method. On 1860 October 1, Brünnow wrote to George P Bond that a telegraph connection was established between the Observatory in Ann Arbor and the Lake Survey at Detroit (Brünnow, 1860a). Meade of the Lake Survey proposed to Brünnow that they work together to determine the precise longitude of Detroit, and Brünnow eagerly accepted.

In preparation for the collaboration with the Lake Survey, Brünnow made some preliminary observations of Ursa Minor and Hydra on 1861 March 18, 19, and 21. The

Lake Survey's observer, James Carr, made similar observations from the Lake Survey's observatory in Detroit. The official observations commenced on April 2 and April 10, of Hydra, and the work was concluded with observations on May 1, 20, and 21, of Virgo, and other stars. Poe assisted Carr at the Lake Survey's observatory at Detroit. This collaboration between Brünnow and the Lake Survey resulted in the establishment of Detroit as the fundamental reference point for all positional determinations made by the Lake Survey in the Great Lakes region.

Following the observations, as a final step in the process, Brünnow and Carr determined their personal equation on 1861 June 6 and 7 using the Pistor & Martins meridian circle telescope in Ann Arbor. It was often the case that two observers with the same level of experience and ability would differ in their reflex timing when recording data on a chronograph. The rate of difference was nearly the same for all stars observed, and this constant difference was explained as "... a discordance between the eye and ear." (Chauvenet, 1891, II:189). Therefore, when two astronomers worked together on observations of the same stars from different locations, it was necessary to know and adjust for the rate of this difference, which was referred to as their "personal equation."

Personal equations could be determined using several different methods. One method called for an observer to lie on the observer's couch of the meridian circle telescope, look into the eyepiece, and note the time of transit of a particular star as it passed over the first three or four wires of the reticle. The second observer would then quickly slip into place on the couch to observe the same star as it crossed the remaining wires. Data for a dozen stars over the course of an hour were recorded, and the difference of the mean results for the two observers was their personal equation. The act of changing places on the couch was awkward, and could adversely affect the accuracy of the personal equation. An alternate method was sometimes used to obviate this factor. Each observer independently determined the clock correction by observing fundamental stars, and the difference of these corrections, both reduced for clock rate to the same point of reference, was the personal equation. A third method employed a refracting telescope fitted with a micrometer. Stars were observed and noted as they crossed over the wires of the micrometer (Loomis, 1879:80-82).

11.6 Ann Arbor, Michigan ↔ Clinton, New York, 1861

In 1861, Brünnow arranged a collaboration with fellow German astronomer C H F Peters of the Hamilton College Observatory in Clinton, New York (near Utica) to determine the longitude. With a telegraph cable now in place across the Detroit River, and a telegraphic connection established between Ann Arbor and Detroit, it was possible to connect directly with a distant observatory. By comparing the local time difference between Clinton and Ann Arbor, using data transmitted by the telegraph and recorded on chronographs, the distance between the two observatories could be calculated. In 1859, Peters had determined the longitude of his observatory by connecting by telegraph with the observatory at Harvard College. The known longitude at Clinton would enable Brünnow to include in his longitude calculation not only the distance between Ann Arbor and Clinton, but also the previously determined distances between Clinton and Cambridge, Massachusetts and between Cambridge and Greenwich – all the way to the prime meridian.

The establishment of a telegraph connection between Ann Arbor and Clinton was greatly complicated by the Civil War. Telegraph lines were in constant use throughout the night, yet the superintendents of the New York Central Railroad and the Western Telegraph Company allowed the two astronomers, Brünnow and Peters, the use of one wire for two nights, after midnight (Brünnow, 1861:17-18).

The first connection between the Detroit Observatory and Hamilton College Observatory was made on 1861 June 29. The mean time clock at Hamilton College and the sidereal clock at Ann Arbor were transmitted over the telegraph line, with 126 beats of the two clocks recorded on two chronographs (see Figure 13). A second successful telegraph connection was established on July 3. The data they gathered were corrected for error in the precision of the clocks, in collimation and azimuth using the method of least squares, and in level as determined by the spirit level on the meridian circle. The result was a successful determination of the longitude of the Ann Arbor meridian circle, set at $50^m24^s.21 \pm 0.047$ west of Cambridge or $5^h34^m54^s.87$ west of Greenwich. Brünnow (1861:17-18) published the details of this longitude determination in *Astronomical Notices*. This longitude was later corrected to $5^h34^m55^s.27$ west of Greenwich after the value for the Harvard College Observatory's longitude was corrected using the telegraphic method once the Atlantic Cable was operational. Brünnow also determined the latitude of the Detroit Observatory, the value of which was extremely close to the present-day accepted value (University of Michigan, 1951:447).

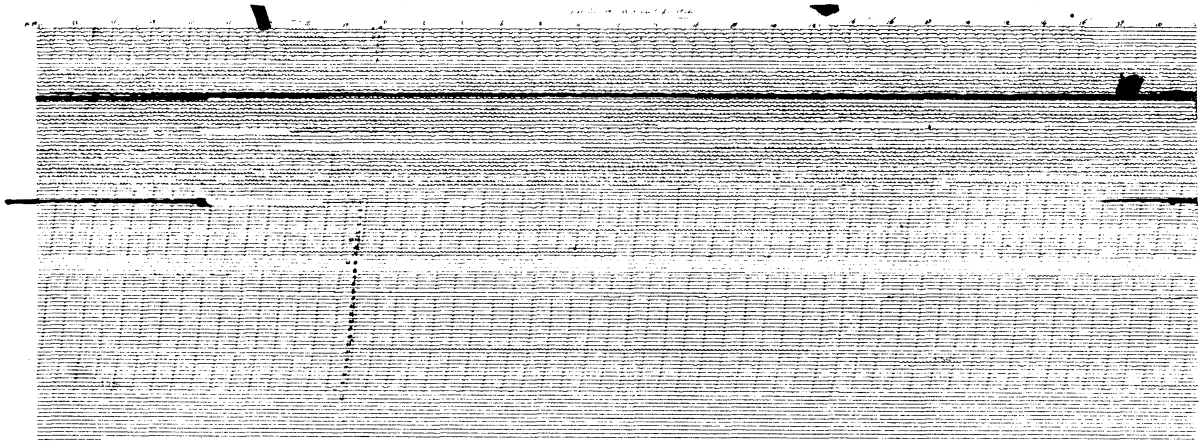


Figure 13. Chronograph sheet dated 1861 June 29 recorded the beats of the clock at Hamilton College Observatory as received at the University of Michigan Detroit Observatory by telegraphic connection. These data were used to determine the longitude of Ann Arbor, Michigan (Courtesy: University of Michigan Detroit Observatory Collection).

11.7 Ann Arbor, Michigan ↔ Green Bay, Wisconsin, 1864

In 1864, the Lake Survey called again upon the services of James C Watson, who was newly appointed as the director of the University of Michigan Detroit Observatory upon Brünnow's resignation and return to Europe. The Lake Survey needed Watson's assistance to determine the longitude of Fort Howard, Wisconsin located at the head of Green Bay. Carr, Assistant Engineer for the Lake Survey, had previously determined the latitude of Fort Howard in 1862, based on seven nights of observations of 30 pairs of stars with a Würdemann transit telescope (Comstock, 1882:627). For the 1864 longitude determination, Lake Survey observers General Raynolds and S W Robinson were at their observatory in Detroit, and C A Young was positioned at Fort Howard. Watson made intermediate observations at Ann Arbor while Orlando B Wheeler,[9] who received his training from Brünnow and Watson at the University of Michigan, observed at Chicago. Each station was equipped with a transit telescope, clock, and chronograph. Watson's observations began on 1864 May 7, with observations of *Polaris*, and continued on July 4, 5, 9, 10, 11, 12, 18, 19, 25, and 29, concluding on July 30.

11.8 Ann Arbor, Michigan ↔ Cambridge, Massachusetts, 1869

In 1869, Watson at Ann Arbor and Samuel P Langley at the Allegheny Observatory in Pittsburgh, Pennsylvania, were invited by the United States Coast Survey to connect by telegraph with the Harvard College Observatory for the purpose of re-verifying the longitude. This effort took place during the Coast Survey's effort to determine longitude between Cambridge, Massachusetts, and San Francisco by way of Omaha, Nebraska, and Salt Lake City, Utah. The exchange of signals between Cambridge and Ann Arbor took place on three nights between 1869 March 15 and March 21, with observers A T Mosman and F Blake stationed in Cambridge and Watson in Ann Arbor. This collaboration was apparently never completed. Langley travelled to Cambridge to determine his personal equation with observer Blake at Harvard, but the Coast Survey report implies that Watson never made the trip to determine his personal equation (United States Coast Survey, 1872:15).

12 CONCLUSION: THE UTILITY OF SCIENCE

Through collaborations with government agencies, university observatories in America played an instrumental role in determining longitude so that land and coastal areas could be accurately surveyed. They formed similarly useful collaborations with private enterprise. The observatories provided precise astronomical time to ensure the safe navigation of ships, passage of trains, transportation of goods and passengers, and synchronous closing of financial markets. They created inventions such as the electric telegraph and chronograph. They implemented technologies such as W C Bond's chronometric expeditions. And, they introduced innovations in scientific instrument and telescope design and optics. To a large extent, the early observatories in this country owed their very existence to the utility of applied astronomical science.

As an example, the creation of the University of Michigan Detroit Observatory was made possible through collaboration with private enterprise. Henry N Walker, a prominent businessman from Detroit, was in the audience the day that University of Michigan president Henry P Tappan delivered his inaugural address in 1852. At the conclusion of Tappan's speech, Walker stepped forward to offer his assistance in raising funds to construct an observatory. Walker, who had significant interests in banking and in the railroad business, identified with Tappan's stated position that scientific endeavours have both a scholarly and an applied value. Tappan said:

> ... can we truly be called a nation, if we cannot posses within ourselves the sources of a literary, scientific, and artistic life as well as of a political and commercial? (Tappan, 1852:16).

Perhaps Walker took particular note when Tappan said:

> We aim not merely to equal, but even to surpass the old nations of the world, in our manufactures, our steamboats, and our railroads. We level the forests in a day, lay down our tracks, and startle the old world with the sounds of our engines.... [We lay] substantial railroads in every direction ... Let us make men as well as houses and railroads. Let us have eternal thoughts circulating among us as well as gold and silver. (Tappan, 1852:51).

Tappan formed a successful collaboration with Walker to raise funds to create the Detroit Observatory. It was a magical matching of applied and basic science interests: Tappan would have his observatory for astronomical instruction and research, and Walker would benefit from the timekeeping a meridian circle telescope and a trained astronomer would provide. Correct time would help keep Walker's trains on schedule and avoid collisions, and financial markets would close at the same time, thereby eliminating any possibility of inappropriate financial gain by one entity over another. The valuable collaboration between the University of Michigan and the citizens of Detroit was so important to the creation of Tappan's new observatory that he named it after the city of its major benefactors (see Whitesell, 1998).

The timekeeping service academic observatories performed for national and local government, and for private enterprise, helped to sustain the observatories. The private observatories generally collected revenue for providing a time service, and most public observatories, including the Detroit Observatory, provided the service at no cost, although this free service no doubt influenced the level of appropriations made by State governments to public universities.

By the 1870s, the national sentiment was that "Astronomers, by their accurate determinations of the places of the sun, the moon, and the stars, [had] given prosperity to commerce and boundless wealth to [the] commercial cities." (Loomis, 1874:52).

The same nineteenth-century tenets continue to apply in the twenty-first century through collaborations formed between universities, the government, and private enterprise. The transfer of technologies developed by universities provides many technical, medical, scientific, and other useful advances to society, and sustenance to the economy. Basic science continues to demonstrate its utility in practical applications – such as in the development of the Global Positioning System (GPS) that can determine longitude with the press of a button – and in ways we have yet to imagine.

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14 NOTES

1 The 1854 Detroit Observatory at the University of Michigan in Ann Arbor was named to honour its principal benefactors from the City of Detroit (and should not to be confused with the United States Lake Survey observatory at Detroit).

2 Edmund Blunt Jr. became Ferdinand Hassler's first assistant in 1832.

3 William A Burt also invented Burt's Typographer, the first typewriter, in 1828.

4 Johann F C Gauss of the Göttingen Observatory, Germany, invented the heliotrope, a small, round mirror the size of a silver dollar, which was used to reflect the Sun's rays a great distance.

5 Sydney Coolidge was killed during the Civil War at the Battle of Chickamagua in 1863 (Jones 1971:117).

6 Mark W Harrington was director of the University of Michigan Detroit Observatory from 1879 to 1891, after which he became the inaugural chief of the U.S. Weather Bureau. His interest in meteorology was developed in Alaska. Marcus Baker graduated from the University of Michigan in 1861. He became a noted cartographer, founding member of the National Geographic Society, and Assistant Secretary of the Carnegie Institution.

7 The Morse register held a fillet of paper that reeled off at a uniform velocity by means of wheels moved by a weight. A pen, which was connected to the armature of an electro-magnet powered by a galvanic battery, recorded data on the paper.

8 The exact date the time service commenced at the Detroit Observatory is not known. The first documented date that confirms a time service was in operation is 1863.

9 Orlando B Wheeler graduated from the University of Michigan in 1861.

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