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THE CENTENARY OF THE PRIME MERIDIAN AND OF INTERNATIONAL STANDARD TIME

In 1884, an international conference was assembled in Washington, D.C., to establish a prime meridian that would be accepted as an international standard. One purpose (Part I) of this article is to commemorate that conference, to explain APL's interest in the centenary and in the subject, and to muse about the prospects for the prime meridian in the next century. The other purpose (Part II) is to describe why the present system of international standard time zones came to be adopted at that conference, although it was many years before most countries recognized the system. In fact, possibly half the people on earth still do not observe standard time.

I. THE PRIME MERIDIAN

EVENTS LEADING TO THE 1884 WASHINGTON CONFERENCE

In the 17th century, prior to the establishment of the Greenwich Observatory, a navigator of the broad ocean areas was faced with the longitude problem. He could make a fair estimate of latitude by measuring the height of the sun at noon or of the North Star. Latitude has a natural reference, the equator; longitude has no such reference. A common tactic was to sail to the desired latitude, then sail along the parallel in the right direction until the proper meridian was reached. In 1598, Philip III of Spain offered 6000 ducats and other benefits for a method to "discover" the longitude.[1] About 1610, the States General of Holland offered 30,000 florins for a solution. None of the aspirants provided a practical solution. It was in this situation in 1674 that LeSieur de St. Pierre approached Charles II of England via an intermediary with a proposal that was met with interest. Late in that year, the King appointed a Royal Commission to study LeSieur's proposal. Enter John Flamsteed (1646-1719), who was recruited as an official assistant to the Commission. He reported that the proposal was theoretically valid but unusable practically because of the lack of the necessary accurate star positions.[2] The King's response was prompt. On March 4, 1675, he appointed Flamsteed as "Astronomical Observer" at a salary of £100 per annum. Sir Christopher Wren, something of an astronomer, selected the site for the observatory on Maze Hill near London overlooking the Thames and completed the building in mid-1676. Flamsteed made his first observations on September 16, 1676. He was to persevere until his death, when two assistants continued the editing and publication of his work. It appeared in 1725 as the *Historia Coelestis Britannica*, a catalog of 2935 stars observed at Greenwich, and it was the standard star catalog for many years. In 1766, the Astronomer Royal, Nevil Maskelyne, published the *Nautical Almanac and Astronomical Ephemeris for the Year 1767* based on the *Historia Coelestis Brittanica*, thus providing a practical method of discovering the longitude and satisfying the 1675 directive of Charles II.[3]

During these plodding years of stellar observation, the urgency of the longitude problem was highlighted by several sea wrecks resulting from navigation problems. Probably the worst occurred on October 22, 1707.[4] A fleet of 21 British naval vessels had left Gibraltar about a month earlier headed for Falmouth. As they approached the entrance to the English Channel, three ships were set apart as convoys. All three were wrecked on reefs off the Isles of Scilly. Almost 2000 men were lost; only 24 survived. It is possible that they could have avoided the disaster if Maskelyne's *Nautical Almanac* had been available.

The country and Parliament were aroused, but it took about 11 years for Parliament to offer prizes for "such Person or Persons as shall Discover the Longitude at Sea." The rewards were £10,000 for determination within 60 nautical miles, £15,000 for reliability within 40 nautical miles, and £20,000 for reliability within 30 nautical miles. Although the French court did not offer any prizes, a private citizen, Rouille de Meslay, included such prizes in his will. He died in 1715, thus activating his prizes about the same time that Parliament acted (1714).

These incentives resulted in two developments: the sextant (1732) and the marine chronometer (1762), which together provided a simple, practical solution not superseded until the 20th century by the advent of electronic navigation aids and satellite navigation. The sextant provided a way to measure the angle between two celestial objects or their distance above the horizon. The marine chronometer provided a reliable way of carrying Greenwich time aboard ship for long voyages without the need for correction.

The sextant is generally attributed to John Hadley (1682-1744).[5] At about the same time, it was also invented by Thomas Godfrey (1704-49), a glazier and self-taught astronomer living in Philadelphia.[6] The chronometer was a much more complicated and lengthy effort. John Harrison (1693-1776), son of a carpenter, turned from the family trade to clockmaking and undertook to win the longitude prize. The major improvements in the clock mechanism were to make the rate independent of temperature changes and to make it free of any changes while it was being wound. Four clocks were completed between 1735 and 1761. A series of trials showed the final version fully acceptable. Parliament temporized on making an award; in desperation, Harrison appealed to the young King George III. The King arranged for the latest model to be tested at his private observatory and finally prevailed on Parliament to make the fullest award by a bill in June 1773. It should be noted, on the other side of the controversy, that Parliament had subsidized Harrison by substantial grants from 1735-61 while the model was being improved. Counting these advances, the total award was £22,500.[7]

In France, Pierre LeRoy (1717-85) produced his first version of a marine chronometer in 1756. The final improved version was completed in 1766, about 5 years after Harrison's final version.

With the sextant and chronometer on hand, the determination of longitude was simplified to determining local noon by noting when the sun was at its highest, using the sextant; at the same moment, the chronometer was read to determine the corresponding time at Greenwich. The difference between 12 noon and local Greenwich time was then converted into longitude at the rate of 15 degrees per hour and labeled east or west according to whether local Greenwich time was earlier or later than 12 noon.

It should be noted that as the 19th century progressed, there developed a marked inclination for shipping to rely on British navigation aids (such as the *Nautical Almanac*), on British charts, and on Greenwich time. There were at least 11 prime meridians used by the ships of various countries. Following is a list of these meridians and the percentages of ships and tonnage that used each.[8]

Prime Meridian	*Ships* (%)	*Tonnage* (%)
Greenwich	65	72
Paris	10	8
Cadiz	5	3
Naples	4	4
Christiana	4	3
Ferro	2	3
Pulkowa	1½	1½
Stockholm	1½	1
Lisbon	1	1
Copenhagen	1	½
Rio de Janeiro	½	½
Miscellaneous	4½	2½

The preference for the Greenwich meridian is explained by the reputation for reliability and correctness developed by Greenwich time and various Greenwich Observatory publications. Undoubtedly, this preference was affected by the earlier availability of Greenwich navigational data. Whatever the reasons, there was no doubt that a standard prime meridian would be a benefit to the entire shipping establishment.

At the Third International Geographical Congress at Venice in September 1881, the topic "Establishment of a universal prime meridian and uniform standard of time" was on the agenda, but no action was taken. However, at the Seventh International Geodesic Conference at Rome in October 1883, discussions resulted in several resolutions that were to be revived later.[9] As a result of the Venice conference, the U.S. Congress passed a bill on August 3, 1882, authorizing President Chester A. Arthur to call an international conference. Washington was proposed as a meeting place because the United States possessed "the greatest longitudinal extension of any country traversed by railway and telegraph lines." Responses being favorable, invitations were issued on December 1, 1883, to assemble in Washington on October 1, 1884.[10]

Twenty-five countries sent 41 delegates to the meetings, which lasted from October 1 to November 1, 1884. The first meeting chose Adm. C. R. P. Rodgers, USN, as president of the conference and agreed on the rule "one country, one vote."[11] (See boxed insert.) Although a number of unexpected proposals came up, the considerable advantage of maintaining the status quo overcame the proposed innovations. A review of the voting record shows a substantial majority for each vote on the seven resolutions. Only two resolutions produced significant abstentions. One was the resolution to count longitude east positive from 0° to 180° east and longitude west negative from 0° to 180° west. The other was the resolution to start the mean solar day at mean midnight of the initial meridian and to count it from zero up to 24 hours.

APL'S CONTRIBUTIONS

We have now arrived at APL's interest in this centennial and in the Greenwich Observatory. APL developed the TRANSIT satellite navigational system in the 1960s for the Navy, and it is currently installed in over 60,000 naval, commercial, and private vessels. During the development of TRANSIT, a question arose about the correctness of the system's longitude reference, and it was decided to determine the longitude of the Greenwich meridian by satellite. The longitude was not zero,[12] as might be expected, but was nearly so. The explanation involves a small excursion into geodesy.

We start with an imaginary terrestrial surface called the geoid. It is defined as an "equipotential surface" of the gravity field, one that closely conforms to the undisturbed surface of the oceans; over land areas, it conforms to a surface defined by imaginary narrow channels in direct communication with the ocean. The

RESOLUTION AT WASHINGTON CONFERENCE OF OCTOBER 1, 1884

I That it is the opinion of this Congress it is desirable to adopt a single prime meridian for all nations, in place of the multiplicity of initial meridians which now exist.

II That the Conference proposes to the Governments here represented the adoption of the meridian passing through the center of the transit instrument at the Observatory of Greenwich as the initial meridian for longitude.

III That from this meridian longitude shall be counted in two directions up to 180 degrees, east longitude being plus and west longitude minus.

IV That the conference proposes the adoption of a universal day for all purposes for which it may be found convenient, and which shall not interfere with the use of local or other standard time where desirable.

V That this universal day is to be a mean solar day; is to begin for all the world at the moment of mean midnight of the initial meridian coinciding with the beginning of the civil day and date of that meridian; and is to be counted from zero to twenty-four hours.

VI That the Conference expresses the hope that as soon as may be practicable the astronomical and nautical days will be arranged everywhere to begin at mean midnight.

VII That the Conference expresses the hope that the technical studies designed to regulate and extend the application of the decimal system to the division of angular space and of time shall be resumed, so as to permit the extension of this application to all cases in which it presents real advantages.

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Voting Record Summary

Resolution	I	II	III	IV	V	VI	VII
Ayes	21	22	14	23	15		21
Noes	0	1	5	0	2		0
Abstentions	0	2	6	2	7		3

Resolution VI carried without division.

Denmark accepted the invitation but sent no representative.

Representatives not present account for totals less than 25 in each vote.

gravity vector (e.g., the plumb-bob vertical) is perpendicular to the geoid. The mathematical description of the geoid is a central problem in geodesy, and satellites have greatly aided in improving this description. Prior to the advent of satellites, the approach to the problem required assembling surface gravity measurements over the earth and fitting a spherical harmonic expansion to the data. Because much of the data was derived from local measurements, it was customary to generate a portion of the geoid and fit an ellipsoid (see Fig. 1) to the section. The resulting "reference" ellipsoid was then an important part of a "local datum"; "local" in this context means within a single country or continent. For example, a local datum is a local coordinate system, intensively used as a basis of local surveying; there is a "North American datum," a "European datum," etc. These local datums were (are) compromises; more convenient would be a "world datum," a single earth-centered coordinate system that could be used to define the coordinates of all points on earth. Otherwise—and this is the current situation—we have to be concerned with the tedious relationships (coordinate transformations) among the various local datums.

Satellites, observed by a network of ground stations, furnished a key to a solution of the problem, and, starting in the 1960s, world datums began to appear. The one derived for the TRANSIT system[13] was one of the first. It should be noted that a level (either a bubble level or plumb bob) finds the direction of the vertical to the geoid, not the vertical to the ellipsoid. The deflection of the vertical (of the ellipsoid) relative to the geoid vertical is generally less than 10 arc-

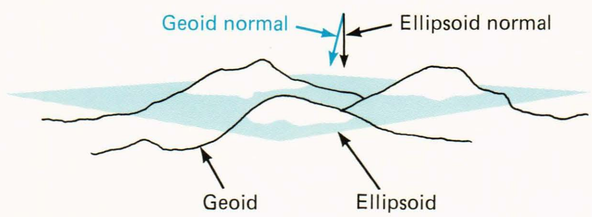

Figure 1 — The geoid is an equipotential surface of the earth's gravity field that coincides with mean sea level. The oblate ellipsoid is a smooth approximation to the geoid. Deviations of the geoid from the best fitting (global) ellipsoid are everywhere 110 meters or less.

seconds but may be as large as 30 arc-seconds. The local or plumb-bob vertical is the basis for leveling astronomic observing devices, which brings us back to the notion of a meridian. Meridian planes containing the local vertical, the normal to the geoid, and containing a parallel to the polar axis are then "astronomic" meridian planes; one containing the Airy transit at Greenwich is *the* prime meridian, and it has (by definition) a longitude of $0°0'0''$. However, the local vertical in this plane is not perpendicular to the mathematically derived ellipsoid surface. The east-west deflection of the vertical from the ellipsoid normal was found, by our "navigating the meridian," to be $5''.69 \pm 0''.17$ W. The result of the computation may be designated as the deviation of the longitude of the geodetic meridian relative to the astronomic. Incidentally, a confirmation of the above geodetic longitude of the prime meridian appeared in Ref. 14. The geodetic longitude of the Greenwich meridian in the European datum was transformed to a value in the world datum (based on the World Geodetic System WGS72 potential model, which also was used in the figure quoted above) and which yielded a value of 5″.72 W, a remarkable agreement.

There are a number of physical effects that result in an apparent modification of the observed longitude, but they are either predictable or can be measured and corrections made after the fact. Thus, nutation of the earth produces a wobble of the polar axis but a negligible effect on the satellite's orbit. Polar motion, caused by shifting masses within the earth, results in the polar axis wobbling in a rough circle about 30 meters in diameter. In this case, the appearance of a polar *axis* wobble is misleading. Because the effect is due entirely to internal mass shifts and forces, there is almost no change in angular momentum. The polar axis remains fixed in the stellar coordinate system and the earth wobbles about it. In this case, the longitude is corrected back to a Conventional International Origin rather than relying on a peripatetic pole. The correction from the current pole to the Conventional International Origin is computed regularly and disseminated to interested parties by the Bureau Internationale de l'Heure (BIH) in Paris.

This completes the excursion into geodesy. Those interested in further information on the subject are referred to the following texts:

C. E. Ewing and M. M. Mitchell, *Introduction to Geodesy*, American Elsevier Publishing Co., New York (1969);

W. Heiskanen and H. Moritz, *Physical Geodesy*, Freeman Publishing Co., Van Nuys, Calif. (1967);

G. Bomford, *Geodesy*, 4th ed., Clarendon Press, Oxford (1980).

RECENT DEVELOPMENTS

The preoccupation of the Greenwich Observatory with the longitude problem faded in the 19th century, to be replaced by an interest in timekeeping. The Observatory became the source of official time for the British Isles. However, no effort was made to provide wireless time signals. Such signals were provided by other countries, and it became increasingly apparent that discrepancies were present. By 1911, the situation needed correction. France took the initiative and invited governments to send delegates to unify time signals. The representatives of 16 countries assembled on October 15, 1912, and established the BIH to secure the universal use of Greenwich Mean Time. The advent of World War I suspended full ratification of the agreements, but a provisional Bureau continued to operate during the war. In 1957, the Greenwich time functions were transferred to the new Royal Greenwich Observatory at Herstmonceux Castle, northwest of Hastings. The original Greenwich Observatory no longer performs any astronomical functions, and it has become a part of the National Maritime Museum.

The brass strip in the Observatory courtyard is still there. In a traditional sense, an extension of the brass strip passes through the earth's pole. If the earth were a rigid unyielding body, then the strip would be a satisfactory longitude reference for all purposes; it *is* satisfactory for most purposes. The earth is not rigid, and one manifestation of this nonrigidity is "polar motion"; the earth's rotational pole moves slowly relative to the earth's surface. The motion is small, typically a few meters in the course of a year. As a consequence, the brass strip as a simple longitude reference has been supplemented (perhaps supplanted) by the BIH system, a system of tracking stations that monitors the position of the rotational pole.[15] (Some 500 people and 60 observatories are involved in this effort.) The positions of a "fixed pole and meridian" are implicit in the station coordinates used to monitor the position of the rotational pole. The question of consistency between the BIH meridian and the Greenwich meridian immediately arises. Because of the way the former is defined and the nonrigid character of the earth, this is a very difficult issue to decide. The best current information is that the two references differ by about 0.3″ to 0.8″. A discrepancy this small is inconsequential for navigation purposes.

Conceptually, even for a nonrigid earth, we can take and keep the longitude of one point on the surface as zero. Disseminating and using this definition in a consistent manner at other points on a nonrigid earth is a technical problem on the frontier of modern geophysics. Thus the brass strip at Greenwich has not been forgotten but still controls the longitudes of the observing stations reporting to the BIH and thus controls the longitudes of associated sites.

And so, 100 years after the Washington Conference, we consider whether the decisions made there are still fitting and proper or whether intervening developments have made changes desirable. The first question one might pose is "Has there been an organized plea for a change and, if so, what and why?" The second question might be "If so, to what extent has support been generated by those who have an interest or would be affected?" As far as the authors are aware, the answers to both questions are negatives. It is not difficult to understand why. The reasons are the same as those that motivated the conferees in 1884 and have become more compelling in the last 100 years. They may be summarized in a phrase: the status quo. It would have been exceedingly arduous and expensive to choose another prime meridian, and the incentives to do so were vague and of questionable value. The constituencies of the status quo are the holders of a vast library of maps and charts covering the entire globe. The users of the library are the transportation operators of land, sea, and air and, in addition, the construction industry, which plans the buildings, roads, waterways, railroads, and airfields of the world. Added to these are the many landowners whose titles refer back to the prime meridian. This is the constituency that must be convinced that another prime meridian is in its interest. It is no wonder that the conference vote for the Greenwich meridian was so decisive.

There was one proposal in the discussion that had some merit: locate the marker in neutral territory. The one proposed was an island in the Azores. The advantage would be to avoid war damage. Someone pointed out that the Azores belonged to Portugal, nullifying any pretension to neutrality. However, this consideration was addressed in recent years by the revised definition of the Conventional Zero Meridian, determined by the BIH and dependent on numerous observing stations. Thus, the hazard of war damage to the Greenwich mark was countered by distributing the location among many observatories. The duties of the BIH could be reassigned if needed and a new marker located in the same or a different site as the prime meridian based on the "distributed prime meridian." In any event, a physical reference on the prime meridian constitutes a guarantee that the continuing developments in geodesy will have a longitude anchor and not drift away from the Greenwich meridian.

II. INTERNATIONAL STANDARD TIME

INTRODUCTION

In the system of international time zones, we change our watches and clocks by exactly 1 hour when we pass from one zone into the next. Since there are 24 hours in a day, this implies that there are 24 zones. It also implies that there is a prime meridian to whose time all other zone times are referred, with the other times differing by an integral number of hours from the time at the prime meridian.

Standard time zones are a relative newcomer to the world scene. It is said that the system dates from an international conference held in 1884. As we shall see, the choice for a date of adoption is somewhat arbitrary. Nonetheless, if we accept it, 1984 has seen the centenary of the zone system. The system was adopted as late as 1884 because three conditions had to be met before it could come about. Two conditions were technical and the third was political.

The first condition was the technical ability to know at any place the time at any other place in the world, at least within a few seconds. This ability arose in 1762, when a marine chronometer developed and built by John Harrison returned from a round trip across the Atlantic that lasted 5 months. On its return, the error in the chronometer was less than 2 minutes,[16] and the error in crossing the Atlantic was soon reduced to a few seconds. All other time connections could be made by land with, at most, short journeys over water.

The second condition was the demand to have a standard time system. This demand was technical in origin, as will be explained later, and did not arise until the second half of the 19th century.

The third, or political, condition was the willingness of nations to accept as the prime meridian a meridian that did not pass through their own territory. This is a serious condition, and many major nations did not accept the present zone system until well into this century.

TIMEKEEPING

Originally, timekeeping was far from standard; in fact, the word "hour" did not originally mean the 24th part of a day; further, "day" originally meant the interval from sunrise to sunset. "Day" and "night" were originally disconnected intervals and were individually divided into smaller units of time, at least in ancient Egypt and in the western world. Only later did day and night come to be united to make up a single entity that is also called a day. Even now, we can tell only by the context whether "day" refers to the period of light or whether it refers to a full circle of light and dark.

The western world owes its earlier system of timekeeping to the ancient Egyptians.[17] For each time of of the year, the ancient Egyptians used separate sets of stars, which they changed about every 10 days, whose risings divided the night into 12 parts (hours of the night) that were roughly equal. They were doing this before 2000 BC. Only somewhat later, around 1500 BC, do we have firm evidence that they were also dividing the day (the interval from sunrise to sunset) into 12 equal parts (hours of the day) by means of a "shadow clock" that is a crude form of sundial. Still later, by the period between 1200 and 1100 BC, they had developed the concept of a time interval that consisted of a day plus a night, and they divided this larger interval, which we also call a day, into 24 equal parts. We call these equal parts "equinoctial hours" when it is necessary to use two or three kinds of hour in one context. Before the year 1100 BC, we have Egyptian tables that give the length, in equinoctial hours, of daylight and darkness for each month of the year.

Ancient astronomers, as well as modern ones, used a flow of time that is uniform, so they tended to use the day of 24 equal hours. Most people, however, had their lives regulated by the rising and setting of the sun, so they retained the older usage of "hours of the day" and "hours of the night" until nearly the end of the Middle Ages, at least in European society. As evidence of this, we have the fact that the canonical times of prayer, such as matins, primes, and so on, were tied to the times of sunrise and sunset. Also, of course, farming people – and the majority of the people were farmers until recent times – were tied in their activities to the rising and setting of the sun.

For example, the medieval chronicler Gervase of Canterbury[18] copied a source from Canterbury that says of the solar eclipse of March 20, 1140, that it occurred about "*nones* on the 13th day before the calends of April" (and thus on March 20).[19] *Nones* means the ninth hour, and we must ask whether this meant 9 hours after midnight in the modern sense or 9 hours after sunrise in the earlier sense; the two times differ by about 6 hours. Calculation shows that the eclipse came in the middle of the afternoon and therefore at the ninth hour of the day, and *nones* retained this meaning for another century or so after 1140.

It is clear that the length of an hour of the day or night varied with the seasons. At London, for example, the longest hour of the day (at the summer solstice) was about 1⅓ equinoctial hours, and the shortest hour of the day was about two-thirds of an equinoctial hour. This variation is not consistent with the use of stable clocks, and the clocks in use before about the 14th century were changed with the seasons to read hours of the day.[20] This could be done because the clocks were not very accurate.

People before modern times, even astronomers, were usually reluctant to tell us how they determined the time. We know that sundials were used from very early times in the daytime. We have, even from Roman times, collections of gears that seem to have some connection with time. However, it is believed that they were not used to tell the time. Instead, they were planetaria whose function was to give the (geocentric) configuration of the solar system, perhaps referred to the stars, at some specific time. If planetaria were allowed to run freely, instead of being set manually to a specified time, it seems to me that they must have been regulated by the balance between friction and some driving force. In the water clock, which was perhaps the most accurate clock in earlier times, the driving force was supplied by a hydrodynamic head and the friction was supplied by the viscosity of water. In order to make a water clock run at what we call constant speed, one had to try to keep the hydrodynamic head constant, and one also had to try to keep the temperature constant in order to keep the viscosity constant.

The key to a more accurate clock was to use some periodic phenomenon that could be coupled through an escapement to a gear train. Each cycle or half-cycle of the period, the escapement allowed the first gear in the train to advance one tooth. The first periodic device used to drive a clock was a torsion pendulum, which was first installed in a clock in the 14th century. Even the early forms of this clock could keep time with an accuracy of a few minutes per day, and furthermore they could not easily be adjusted to agree with the varying length of an hour of the day. It is probably not a coincidence that the hour of the day (or night) disappeared from ordinary usage about the time that the torsion clock was invented.[21]

Astronomers at least since the ancient Greeks have known that there are two kinds of solar time, namely, true solar time and mean solar time, and the ancient Greeks could calculate the difference between them theoretically. True solar time means time regulated by observation of the true or actual sun. However, the sun does not appear to move in the plane of the earth's equator, and it does not appear to move in a circular orbit with uniform angular velocity. From a combination of these two effects, time kept by the true sun is not uniform. In order to get a uniform measure of time from the sun, we have invented an entity called the mean sun. The mean sun is a point that moves in the plane of the earth's equator at a uniform rate equal to the average rate of the true sun in its orbit, and mean solar time is the time we keep if we base time upon observations of the position of the mean sun.[22] What is called "true time" here is often called "apparent time" in the modern literature.

Thus the length of the true day is not uniform. At the extremes, the length of one true day differs from the length of the preceding true day by about 1 part in 10^5, or about 0.8 second. The difference between mean and true time, at the extremes, can change by about 30 minutes in 3 months, or about 20 seconds per day. The clocks that were developed in the 14th century could easily tell the difference between hours of the day and equinoctial hours, but they were far from being able to tell the difference between mean and true solar time.

Thus, after a clock was regulated as accurately as possible, it was still necessary to set it daily, and the common practice was to set it daily at noon by the sun, perhaps by means of a sundial. Thus the clocks kept true solar time rather than mean time.

The next major improvement in accuracy came with the development of the clock regulated by a gravity pendulum. Galileo discovered the fundamental principle of the gravity pendulum sometime around 1585, but it was not applied to the regulation of a clock until the Dutch astronomer and mathematician Christiaan Huygens did so in 1656. From that time on, the accuracy of clocks and watches improved rapidly, and it was not long until they could keep time more uniformly than the true sun. When it became well established that this was the case, people went to mean rather than true solar time.[23]

To be sure, until rather recently, the true sun was still used as the ultimate reference. But, with the gravity pendulum, it was worth the trouble of consulting a table of the differences between mean and true times and setting the timepiece to mean time rather than true time.

THE NEED FOR STANDARD TIME

However, people in any location, until about a century ago, set their clocks to read the mean time appropriate to their local longitude. At a period in history when rapid long-distance travel did not exist, it was simpler for each locality to use its own mean time instead of trying to set to the mean time of some other locality.

Of course, people within a short distance of a large town might all decide to keep the mean time of the town. Thus there might be a region whose time standard was the mean time of, say, Boston, while there might be another region whose time standard was that of Hartford, less than 150 kilometers away. It is known that there were more than 50 time standards in the United States in 1881,[24] with three or four in the small area of New England alone.

The most important single event in creating a demand for a single time standard may have been one that occurred on May 10, 1869. This was the completion of the first trans-American railroad, at Promontory, Utah, just north of the Great Salt Lake. In the early 1850s, the federal government planned a transcontinental railroad to run approximately along the 32nd parallel of latitude, from Charleston, S.C., through El Paso to San Diego, and the Gadsden Purchase (of the southern parts of New Mexico and Arizona in 1853) was made at least partly for the purpose of providing a straight route for this railroad entirely within U.S. territory. However, the Civil War interfered with the construction of that route, and in 1863 it was decided that the first transcontinental railroad should run near the 42nd parallel. The new construction needed to accomplish this ran only from Omaha, Neb., to Sacramento, Calif., with the Union Pacific building westward from Omaha and the Central Pacific eastward from Sacramento. They met at Promontory, where the final ceremony took place on May 10, 1869. There, between the noses of two locomotives, the last spike, a golden one, was driven.[25] Other transcontinental lines soon followed.

Thus it became possible to travel coast-to-coast in a few days, with the necessity of using the multitude of time standards that then existed. This was a nuisance to passengers who needed to make connections, but it was also dangerous. If a train crew failed to make the frequent time changes correctly, there was serious risk of an accident. Accordingly, there arose a demand for a unified time system for the railroads of the entire country.

Of course, similar problems existed elsewhere, particularly in the western part of Europe. There, Great Britain, at a fairly early date, put all of the island of Great Britain onto Greenwich time, France put all of that country onto the time of the Paris Observatory, and so on. Still, a train traveling from Paris to Istanbul, say, had to make an uncomfortable number of time changes.

There had been some demand for an international time standard before the advent of rapid, long-distance railroading. In particular, individual astronomers, and navigators of oceanic shipping, needed to use an international time standard, but they did not all use the same one. Further, astronomers and navigators by themselves did not have enough political power to bring about agreement on international standards. It is likely that long-distance railroading supplied the necessary increment of demand.

Apparently the first person to propose a uniform time system for the United States, in which all local time would differ by integer hours from some single standard, was Charles F. Dowd, who is described as the principal of a young ladies seminary in Saratoga, N.Y.[26] Dowd, in 1846, first proposed using the meridian of Washington, but he later changed this to the meridian of New York and then to Greenwich. His system is described as being too complicated to be usable, and it was dropped.

The matter was revived in 1881. At a meeting of railway managers of the United States held in October of that year, F. A. P. Barnard and others presented a system that had been developed by W. F. Allen. The managers adopted this system at their meeting in October 1883, to go into effect on November 8, 1883. It is interesting that Allen's system used the meridian of Greenwich, even though there was still no international agreement concerning this meridian.

This action of the railroads did not directly affect other users of time and, in particular, it did not directly affect the hours kept by law courts, by banks, and by other activities that involved a legally defined time. However, all the states soon passed legislation adopting the railroad time as the time to be used for all legally defined times. Thus the railroad system came to be the legal system for the United States.

THE 1884 INTERNATIONAL CONFERENCE ON TIME STANDARDS

An international conference on time standards was convened in Washington in October 1884. It is left to the reader to decide how much effect the action of the American railroads had upon the decision to call this conference, and upon the place where it was held. The conference opened on October 1,[27] and most of that day and the next were spent in electing officers and on other formalities. After these preliminaries, a resolution was presented on October 2, proposing that Greenwich should be adopted as the prime meridian. The French delegation immediately proposed that discussion of this resolution be postponed until October 6, and this was done.

On October 6, France offered a parallel resolution to the effect that the prime meridian should be a neutral one, meaning one that should cross neither Europe nor North America. The basis for this proposal was that the Paris meridian was just as entitled as the Greenwich meridian to be the prime meridian, so the conference should give equal recognition to both by adopting neither.

There was considerable justice in the French proposal. The Paris Observatory was founded in 1667, while the Greenwich Observatory was not founded until 1675, and astronomers of the Paris Observatory had played a leading part in the development of astronomy. The French delegation presented data on the volume of technical publications that used the respective meridians of Greenwich and Paris and found that the number of pages published annually in each case was about equal. The rebuttal based its argument on the volume of commercial shipping.[28] The argument based on commerce won. Of the countries present, 22 voted in favor of Greenwich, San Domingo (the present Dominican Republic) voted against, and France and Brazil abstained.

FATE OF THE CONFERENCE RECOMMENDATIONS

As someone pointed out during the debate, the conference was a conference of technical specialists, and its actions were not binding on any government. In fact, many governments did not follow the votes of their respective delegations for a long time, and it is somewhat arbitrary to choose 1884 as the year when the Greenwich meridian and the accompanying zone system were adopted. One might as well choose 1883, when the zone system based on Greenwich was adopted for the first time by any country other than Great Britain.[29] Or one might choose any one of several years later than 1884. In 1905, 21 years after the conference, for example, France, Portugal, Holland, Greece, Turkey, Russia, Ireland, and most of Central and South America still did not accept the Greenwich meridian as their prime meridian.[30] Or we could pick the year when all of western Europe, say, had adopted Greenwich as the prime meridian.

I believe that by now most major countries have adopted Greenwich for their prime meridian, at least tacitly. "Tacitly" is certainly the word to apply to France. France first reacted to the conference of 1884 by giving the meridian of the Paris Observatory the status of law. Then, on February 24, 1898, the French Chamber of Deputies adopted and sent to the Senate a bill saying that French standard time should be the time of the meridian of Paris, diminished by 9 minutes and 21 seconds; this is just the difference between the times of the meridians of Paris and Greenwich. The Senate held the bill for 12 years before adopting it, to be effective on March 9, 1911. Not until August 9, 1978, did France adopt "universal time, coordinated" without qualification. It should be noted that "universal time, coordinated" is defined without explicit reference to Greenwich; it is a type of atomic time.

While every area now recognizes the Greenwich meridian, at least tacitly, it does not follow that every country keeps standard time. To review the situation, let us say that an area keeps time h. By this, we mean that local time equals Greenwich time $+h$. If every area kept standard time, h would everywhere be an integral number of hours. h would be 0 from longitudes 7½° west to 7½° east, h would be +1 hour from longitudes 7½° to 22½°, and so on.

The map of time zones (Fig. 2) shows that the time is far from standard, even today. The map was published in 1983, and probably reflects the situation in 1980, allowing for necessary delays in publication. Such a map has shown many changes since 1945, some of increasing and others of decreasing standardization.

In the direction of increased standardization, h is everywhere either an integer or half an integer. Saudi Arabia has changed from keeping true solar time, for which there is no value of h, to keeping h = 3 hours, and it is certainly understandable to have the few small areas outside this range keep the same time as the rest of the country. Liberia has changed from h = −44 minutes to 0; it should have h = −1 hour. Afghanistan has changed from 4 hours 26 minutes to 4½ hours; it is split between the zones with h = 4 and h = 5 hours.

In the opposite direction, China was divided into zones of h = 6 to h = 8 hours. The westernmost part properly has h = 5 hours, but again we can understand shifting the boundary slightly for ease of administration. Now, though, the whole country officially keeps h = 8 hours, but one cannot help wondering whether people in the western part actually get up and go to bed at the same time as those in the east.

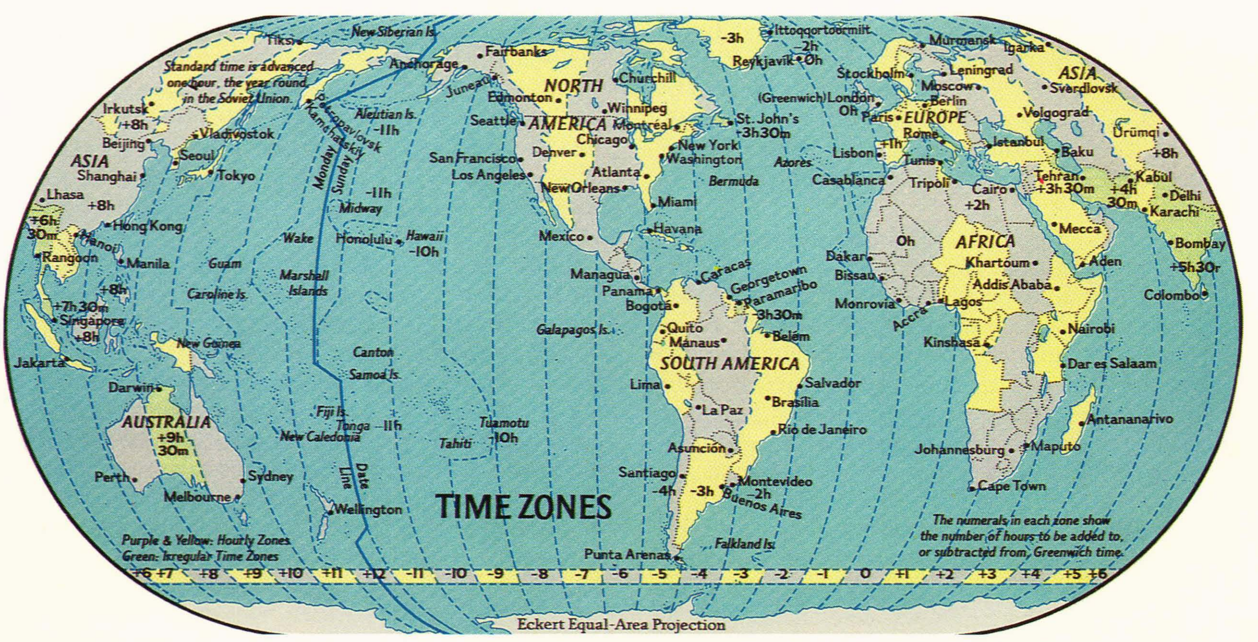

Figure 2 — Map of time zones (taken from the map of the world prepared by the National Geographic Society, as published in 1983, and reproduced here through the courtesy of the Society).

Argentina, Chile, central Australia, and a few small areas elsewhere do not keep the value of h that is appropriate to their longitudes. Chile is entirely in the zone with $h = -5$ hours, but it keeps -4 hours. Argentina geographically has $h = -4$ hours almost everywhere, but it keeps -3 hours. The map shows Siberia divided into zones that are reasonable approximations of the standard ones, given the presence of natural boundaries such as major rivers. However, as a note on the map says, every place in the Soviet Union keeps h to be 1 hour greater than the map shows. All in all, it may be that half the population of the earth keeps a value of h that is not standard for its longitude, and there is no sign that this situation is changing.

REFERENCES and NOTES

[1] D. Howse, *Greenwich Time and the Discovery of the Longitude*, Oxford University Press, p. 12 (1980).
[2] Ibid., p. 27.
[3] Ibid., p. 66.
[4] Ibid., p. 45.
[5] Ibid., p. 58.
[6] Ibid., p. 59.
[7] Ibid., p. 72.
[8] Ibid., p. 141.
[9] Ibid., p. 136.
[10] Ibid., p. 138.
[11] *New York Times,* p. 5 (Oct 3, 1884).
[12] S. C. Dillon, G. Gebel, and L. L. Pryor, "Navigation at the Prime Meridian Revisited," *Navigation: J. Inst. Navig.* **24**, 264-266 (Fall 1977).
[13] H. D. Black, "The Transit System 1977: Performance, Plans and Potential," *Proc. R. Soc. London* **A 294,** 217-236 (1980).
[14] G. Bomford, *Geodesy,* 4th ed., Clarendon Press, p. 612 (1980).
[15] M. Feissel, "Determination of Earth Rotation Parameters by the Bureau Internationale de l'Heure, 1962-1979," *Bull. Geod.* **V54,** 81-102 (1980).
[16] See the articles on John Harrison, on navigation, or on chronometry in any encyclopedia.
[17] R. A. Parker, "Ancient Egyptian Astronomy," *Philos. Trans. R. Soc. London* **A276,** 51-65 (1974).
[18] Gervase of Canterbury, *Chronica* (ca. 1199). There is an edition with preface and notes by William Stubbs in *Rerum Britannicarum Medii Aevi Scriptores,* No. 73, **1**, Longman & Co., London (1879).
[19] *Nones* is derived from the Latin word for "ninth," and it was used in the medieval Latin literature to mean the ninth hour of the day. This was the time midway between noon and sunset. It was the hour of one of the canonical services, and it was the hour at which most people took their main meal until the late Middle Ages. In the 13th and 14th centuries, people began to shift their main meal to the time we call 12:00, but they continued to call this time *nones. Nones* eventually changed into our word "noon," which, though it now means 12 hours, originally meant 9 hours.
[20] Since an hour of the day differed from an hour of the night except at the equinoxes, a person who wanted to read the time at night needed a different timekeeper from the one he used in the daytime unless he made hurried adjustments at sunset and sunrise. However, few people in earlier times needed to read the hour at night.
[21] We cannot say that all clocks made during the next few centuries were regulated by a torsion pendulum; we do not know. It may be that the competition of the torsion clock stimulated the further development of earlier types of clocks, and that the latter reached their highest levels after the torsion clock came in. In a similar way, the commercial sailing ship reached its highest development long after the steamship was invented.
[22] Of course, when we use the mean sun, we actually observe the true sun and correct its position by the theoretically calculated difference. The definition of the mean sun leaves room for an arbitrary constant in the difference between mean and true time. We define this constant so that the average difference is zero. Ancient and medieval astronomers adopted definitions that differ both from the modern one and from each other.
[23] Saudi Arabia was the last country to adhere to true solar time. It did not adopt mean time until some years after World War II. Many religions still use true solar time for timing religious observances.
[24] J. S. Allen, *Standard Time in North America 1883-1903,* American Railway Association, New York (1904).
[25] All sources agree about the place and date and about the golden spike, but there is considerable disagreement about who drove the last spike. One source says on one page that it was driven by Governor Stanford of California, and then contradicts itself two pages later by saying that it was driven by officials of the two railroads. It was probably driven into a prepared hole by a number of dignitaries present and was later removed and replaced by a regular spike.
[26] See the book by Allen that is cited in Ref. 24. The catalog card for this book says that it is by J. S. Allen, but the book itself has no evidence of this. On both the spine and the title page, the author is given as W. F. Allen, and the main purpose of the book is obviously an attempt to prove that W. F. Allen, rather than Dowd, should receive the credit for the system that was adopted.
[27] *Protocols of the International Conference at Washington for the Purpose of Fixing a Prime Meridian and a Universal Day,* Gibson Brothers, Washington, D.C. (1884).
[28] One wonders how much of this predominance was based on the volume of British shipping, how much on the fact that the British discovered the first accurate method of determining longitude at sea, and how much on other factors.
[29] In fact, by the end of 1883, our system of zone time was international. At least two countries, namely Great Britain and the United States, were using zone time based on the Greenwich meridian.
[30] D. Howse, op. cit.

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