

The Greenwich Meridian

...where east meets west

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WGS84 and the Greenwich Meridian

When visitors to the Royal Observatory, Greenwich stand astride the Meridian, they are often perplexed to discover that their GPS does not give their longitude as zero. Likewise, users of Google Earth are sometimes surprised to see that the Meridian as marked, appears to pass around 100 m to the east of where they expected.

The explanation for these apparent anomalies is rooted in the history of longitude determination, the irregular shape of the Earth and a switch from astronomically determined longitudes to geodetic ones.

Precision measurements before the space age

From the earliest of times, it was a priority for astronomers to get an accurate determination of the difference in longitude of their observatories. Of particular importance was the longitude difference of the Greenwich and Paris Observatories. To this end, at least 18 different determinations were made between the 1690s and the start of the 1920s. Each was a major undertaking. Most were astronomical and involved the measurement of the time difference. Those made in 1790, 1791 and 1828 were trigonometrical.

The first attempt to accurately fix the relative longitude of Greenwich and an American observatory, (Harvard Observatory in Cambridge, Massachusetts), took place in the 1840s when nearly four hundred chronometers were transported back and forth across the Atlantic. Following the laying of the first transatlantic cable, the time difference, and hence longitude difference between the two observatories, was determined with even greater precision by telegraphic means in 1866.

The uneven Earth

When the Royal Observatory was founded back in 1675, it was widely believed that the Earth was spherical. This notion was challenged by Newton with the publication of the third volume of his Principia in 1687 in which he hypothesized that the Earth was an oblate spheroid, also known as an ellipsoid, the shape generated by spinning an ellipse on its minor axis. He estimated the equatorial diameter would differ from the polar by about 1 part in 230. The parameters of the ellipsoid have since been refined, but the ellipsoid is not a perfect fit either.

The Earth not only has a surface which is far from uniform, but the distribution of mass within it is uneven. Because of this, the size and direction of the Earth's gravitational field varies from one place to another.

From the early 1700s until the 1980s, time (and hence longitude) was determined with the aid of specialist telescopes. At Greenwich, transit telescopes were used to start with but these were superseded in the 1950s by the [Danjon Prismatic Astrolabe](#) and the [Photographic Zenith Tube](#). Similar instruments were used at other observatories. Each required levelling. This was done with a spirit level in the case of the transit telescopes and with a tray of mercury in the case of the Danjon Prismatic Astrolabe and the Photographic Zenith Tube. The measurements made with all three instrumental types were realised with respect to the local vertical and were thus affected by local gravity.

The advent of satellite technology enabled measurements to be made with reference to the Earth's centre of mass rather than the local vertical. It was this change from measuring astronomical longitudes to measuring geodetic ones that caused the apparent shift of the Meridian at Greenwich.

Why the Meridian moved

Surprisingly, it took until 2015 for the scientific community to provide the first proper analysis of why the Zero Meridian shifted. Written by Stephen Malys, John H Seago, Nikolaos K Palvis, P Kenneth Seidelmann and George H Kaplan, under the title of [Why the Greenwich meridian moved](#). Published on 1 August 2015, in the Journal of Geodesy, it was much commented on in the global press. The authors' conclusions are reproduced below:

'Zero longitude is the terrestrial origin for Universal Time (UT1), a realization of mean solar time at Greenwich used to define the rotation angle of the Earth in space. The 102-m offset between the Airy Transit Circle and zero longitude indicated by a GNSS receiver is attributable to the fact that continuity in the UT1 time series was maintained in the BIH reference frames, as geodetic longitudes replaced astronomical longitudes when space-geodetic methods were introduced. This continuity condition constrained the BTS 84, and consequentially, the ITRF zero meridian plane, to be practically parallel to the orientation of the astronomical prime meridian through Airy's instrument that is aligned to local gravity. Extended to infinity, these parallel meridian planes sweep past the same stars simultaneously, so that both planes indicate the same astronomical time (UT1). The difference between precise GNSS coordinates and astronomically determined coordinates everywhere remains a localized gravity effect due to the deflection of the vertical; thus, no systematic rotation of global longitudes occurred between the former astronomical system and the current geodetic system.

Because the value of the DoV [deflection of the vertical] at Greenwich and the continuity constraint on UT1 were the primary factors that influenced the current location of the ITRF zero meridian, the 1884 recommendation of a prime meridian based on the "Observatory in Greenwich" has been practically maintained to the present by passing the zero meridian plane through the center of mass of the Earth, rather than through the center of the Airy Transit Circle. Modern, high-resolution global gravitational models of the Earth confirm that the local slope of the geoid at Greenwich is of the proper sign and magnitude to support this interpretation, conclusive to within the accuracy of the deflection model ($\pm 0.5''$ 1σ in longitude for the EGM2008 model).'

Local mapping

Most accurate maps show only a small part of the Earth's surface. Before the space age, when choosing an ellipsoid to represent the shape of the Earth, it was the practice to pick one whose surface had a good alignment with reality over the area of the map. In the UK for example, the maps produced by the Ordnance Survey were (and still are) based on the 'Airy Ellipsoid' – an ellipsoid defined by the seventh Astronomer Royal George Airy in 1830. The chosen ellipsoids differed slightly in centre position and orientation as well as in size and shape.

Some ellipsoids and their dates of adoption (from Wikipedia)

Reference ellipsoid name	Equatorial radius (m)	Polar radius (m)	Inverse flattening	Where used
Airy (1830)	6,377,563.396	6,356,256.909	299.3249646	Britain (OSGB36)
Clarke (1866)	6,378,206.4	6,356,583.8	294.9786982	North America
Clarke (1878)	6,378,190	6,356,456	293.4659980	North America
NAD 27 (1927)	6,378,206.4	6,356,583.800	294.978698208	North America
NAD83 (1983)	6,378,137	6,356,752.3	298.257024899	North America
WGS84 (1984)	6,378,137	6,356,752.3142	298.257223563	Globally

Until the advent of GPS, local datums were only ever used in a local context. Although usually inappropriate to do so, it is possible with GPS to set a receiver to get a latitude and longitude fix anywhere in the world in any of the different datums. The precise latitude and longitude of a place will vary with the particular coordinate system or datum that is used. Paradoxically, as we have already seen, this also applies to the Airy Transit Circle, whose longitude by definition one might reasonably expect to be zero. The difference between the co-ordinates on different datums also varies from place to place. Most datums agree with each other to within half a kilometre or so. The most commonly used in the UK are OSGB36 & WGS84.

Continental drift and plate tectonics

At the time of the International Meridian Conference in 1884, the concepts of continental drift and plate tectonics did not exist. The first evidence of plate movement came in the mid 1950's as the space age was about to begin. The Earth's tectonic plates move relative to one another at about the same rate at which human finger nails grow – not much on a day to day basis, but a substantial amount over a period of decades and centuries. The International Terrestrial Reference Frame (ITRF), which defines the International Meridian and poles, is based on the combination of sets of station coordinates and velocities derived from a variety of different types of observations: Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Lunar Laser Ranging (LLR). Data from Global Positioning System (GPS) was introduced in 1991 and from Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) in 1994. The International Reference Meridian and Poles and, hence the WGS84 datum, are stationary with respect to the average motion of the Earth's crustal plates. As a consequence, all individual locations are in motion relative to them. In the UK, WGS84 latitudes and longitudes are changing at about 2.5 cm per year in a north-easterly direction. In 1989, the International Reference Meridian passed an estimated 102.478 m to the east of the Airy Transit Circle at Greenwich.

Further reading

Rear Admiral Robert W. Knox, Precise determination of Longitude in the United States, Geographical Review, Vol 47, No. 4 (Oct 1957), pp.555–563 American Geographical Society.

G. Gebel and B. Matthews, Navigation at the Prime Meridian, Navigation: Journal of the Institute of Navigation (Washington, DC) 18/2 (Summer 1971) pp.141–146.

Ordnance Survey – [A guide to coordinate systems in Great Britain](#) (downloads as pdf)

Malys, Stephen; Seago, John H.; Palvis, Nikolaos K.; Seidelmann, P. Kenneth; Kaplan, George H. (1 August 2015). [Why the Greenwich meridian moved](#). Journal of Geodesy.

Acknowledgements

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