



NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Know the Earth... Show the Way... Understand the World

Why the Greenwich Meridian Moved

Stephen Malys

NGA Senior Scientist for Geodesy and Geophysics

3 November, 2015



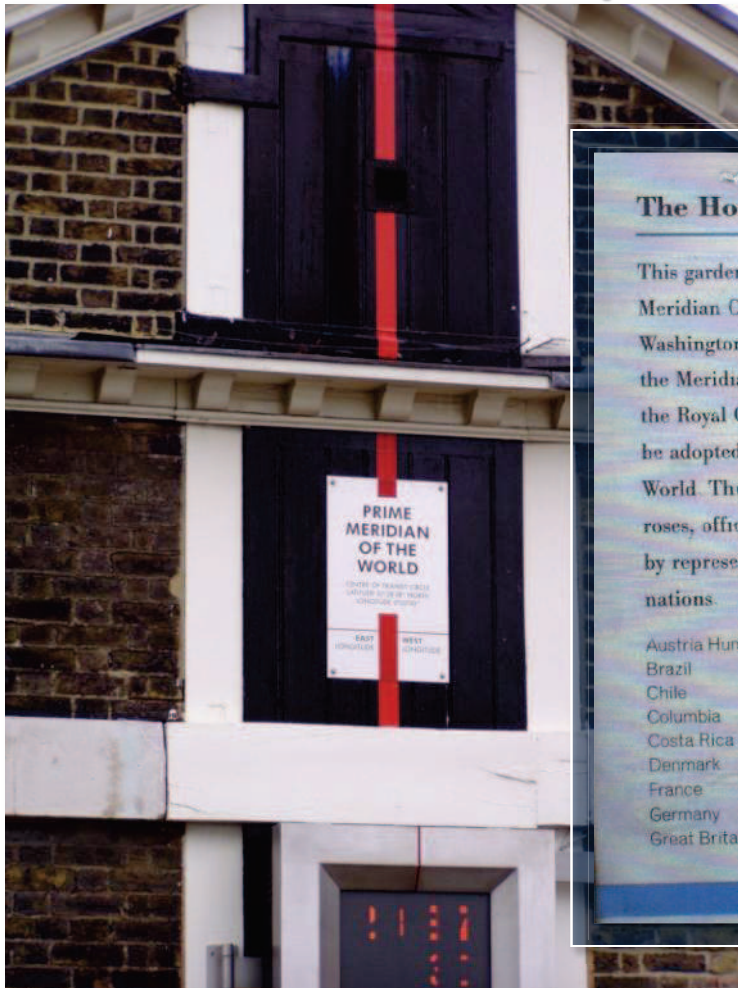


Sir George Airy (1801-1892)
7th Astronomer Royal

https://en.wikipedia.org/wiki/George_Biddell_Airy



Prime Meridian (0° Longitude...Greenwich Meridian)



The Home of Time Garden

This garden commemorates the International Meridian Conference of 1884, held in Washington DC, at which it was voted that the Meridian of longitude passing through the Royal Observatory at Greenwich should be adopted as the Prime Meridian of the World. The garden contains Home of Time roses, officially planted on 1 October 1998 by representatives of the original voting nations.

Austria Hungary	Guatemala	San Domingo
Brazil	Hawaii	Salvador
Chile	Italy	Spain
Columbia	Japan	Sweden (with Norway)
Costa Rica	Liberia	Switzerland
Denmark	Mexico	Turkey
France	Netherlands	United States
Germany	Paraguay	Venezuela
Great Britain	Russia	

ROYAL OBSERVATORY GREENWICH

International Meridian Conference of 1884





NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY
Know the Earth... Show the Way... Understand the World

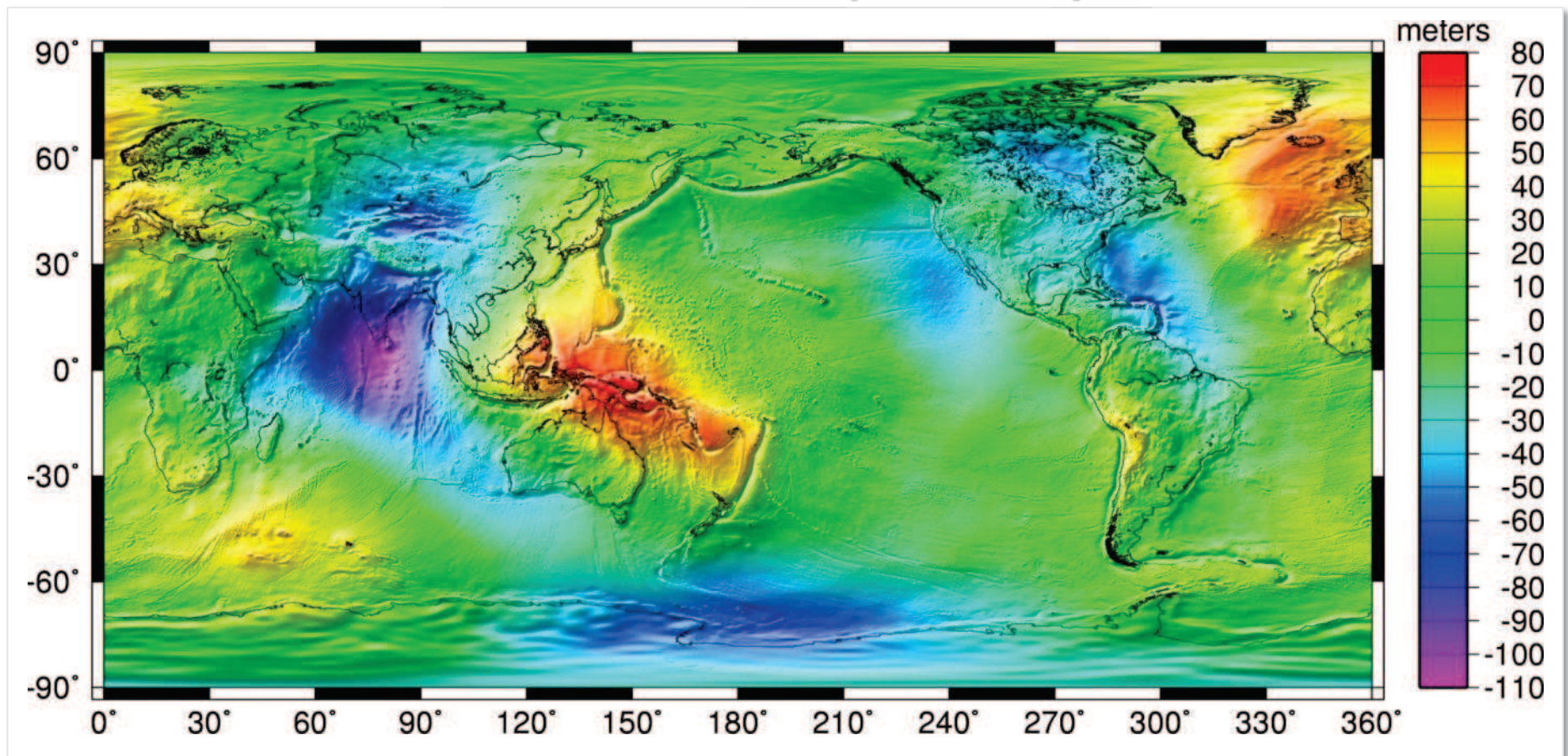
The Airy meridian (dotted line) and the ITRF and WGS 84 Zero Meridian (solid line)



Imagery © 2014 Google Maps, Infoterra Ltd & Bluesky.



Geoid Undulations from the Earth Gravitational Model 2008 (EGM08)





A Global Potential Field and its Representation

The gravitational field generated by a mass distribution can be described *completely* using a scalar function of position called potential.

Gravitational Potential

Potential Coefficients

$$V(r, \theta, \lambda) = \frac{GM}{R} \left[1 + \sum_{n=2}^{\infty} \left(\frac{R}{r} \right)^{n+1} \sum_{m=-n}^n C_{nm} \cdot Y_{nm}(\theta, \lambda) \right]$$

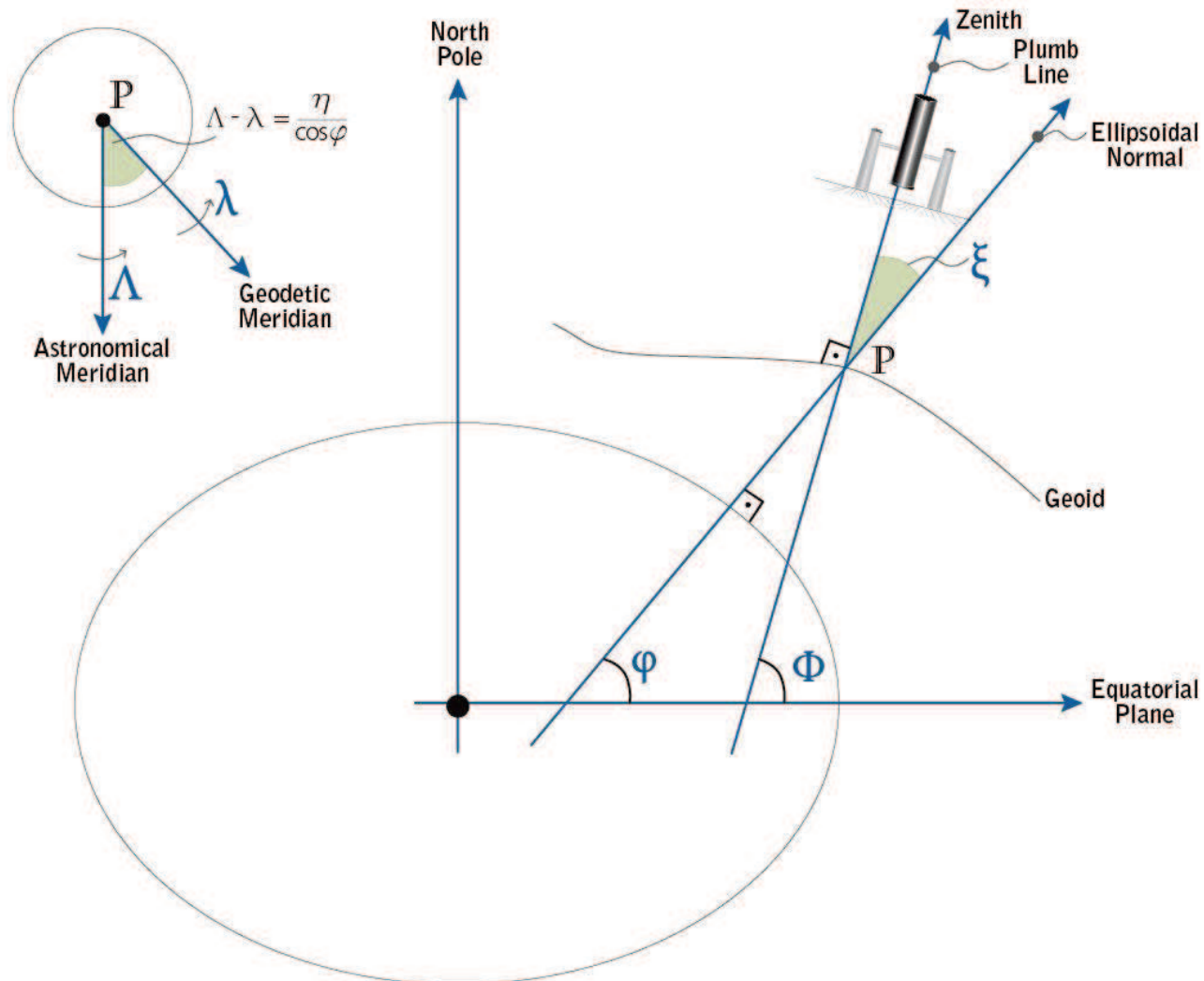
Introduced by Gauss (1839) , Clairaut and Stokes (~1840) then by Helmert (1884)

For practical application, truncate “∞” to some maximum degree “Nmax”.

- 1839**, C.F. Gauss Nmax = 4 (‘WMM 39’) ⇒ **14** Magnetic Pot. Coeff.
- 1960**, I. Fisher Nmax = 13 (Mod Mercury) ⇒ **192** Gravitational Pot. Coeff.
- 1998**, F. Lemoine et.al. Nmax = 360 (EGM96) ⇒ **130,317** Gravitational Pot. Coeff.
- 2012**, N. Pavlis et.al. Nmax = 2160 (EGM08) ⇒ **4,669,917** Gravitational Pot. Coeff.

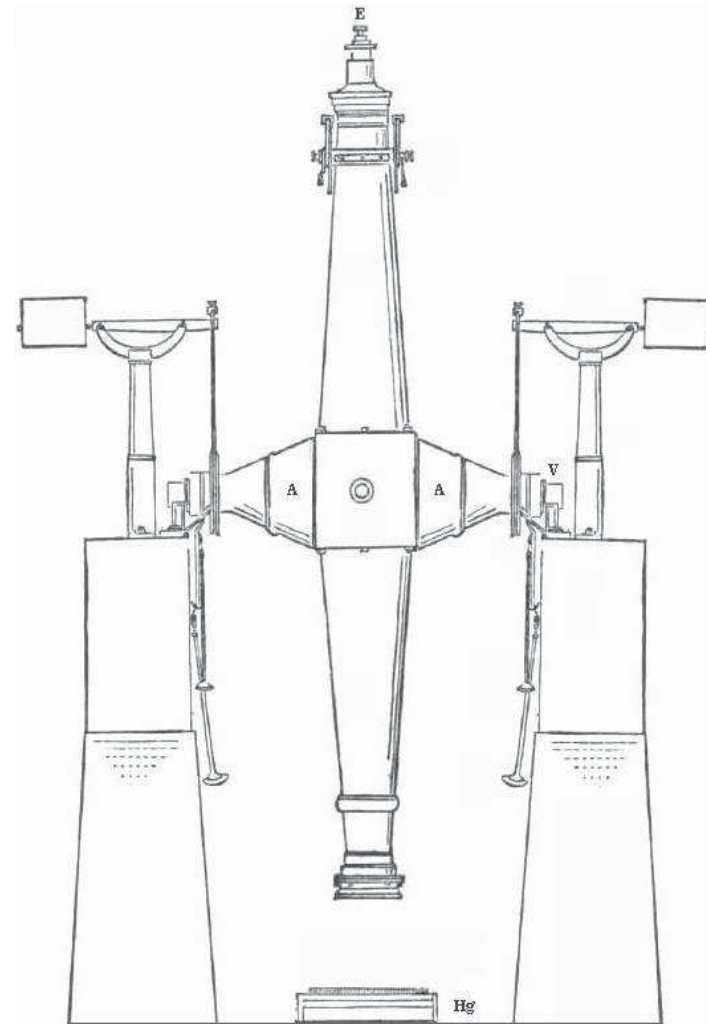
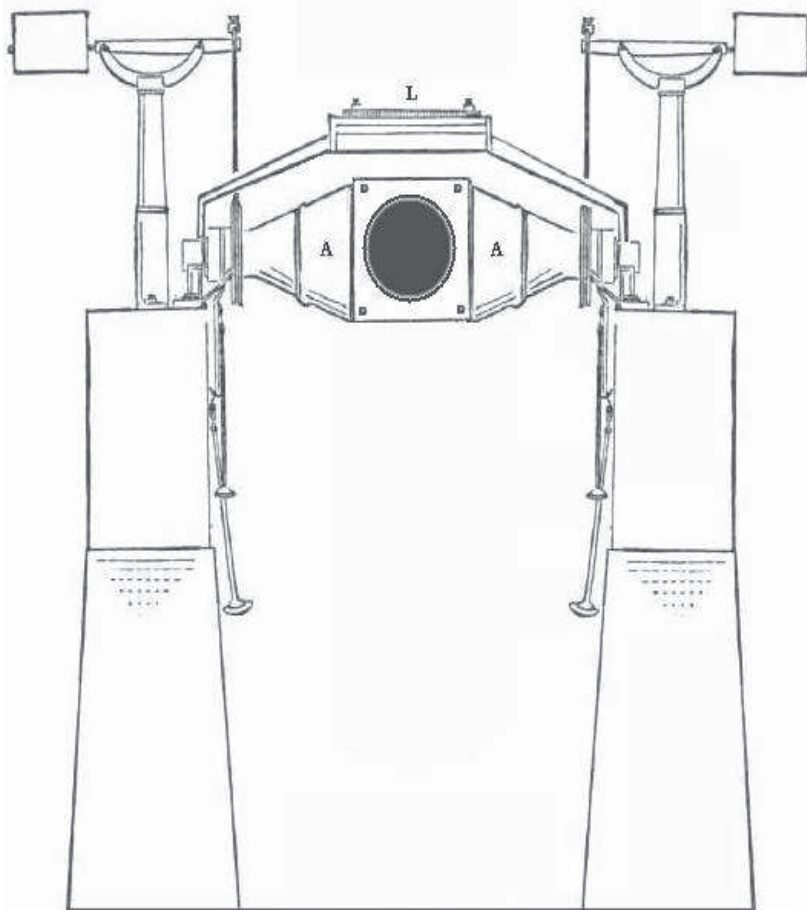


Deflection of the Vertical (η, ξ)





Schematic of a Typical Transit Circle



Adapted from: Norton WA (1872) A Treatise on Astronomy, Spherical and Physical, 4th edn. John Wiley & Son, New York, p 31



BIH Terrestrial System 1984 (BTS 84)

Original WGS 84 reference frame was created by Transforming NSWC 9Z2 into BTS 84

Table 1 - BIH TERRESTRIAL

Name	CONTRIBUTING NETWORKS			Nb of coloc. sites	Status of the transformation parameters		
	Set of station Coordinates	Time span			Centre	Scale	Orient.
RN	SSC(NGS) 83 R 01	1980-1984	11	free	free	free	
RJ	SSC(JPL) 83 R 05	1971-1983	5	free	free	free	
MJ	SSC(JPL) 84 M 01	1970-1984	2	fixed	free	free	
LC	SSC(CSR) 84 L 01	1976-1984	27	fixed	fixed	free	
DM	SSC(DMA) 77 D 01	1975-1984	34	free	free	free	

TABLE 3 - TRANSFORMATION BETWEEN THE INDIVIDUAL TERRESTRIAL SYSTEMS AND THE BTS

NETWORK	SSC	T1	T2	T3	D	R1	R2	R3
		cm	cm	cm	10 ⁻⁸	0.001"	0.001"	0.001"
RN	SSC(NGS) 83 R 01	165.2	-94.9	47.1	-4.4	-5.2	8.0	-5.7
RJ	SSC(JPL) 83 R 05	10.1	-36.8	-15.1	2.8	-8.5	-5.0	-7.8
MJ	SSC(JPL) 84 M 01	0.0	0.0	0.0	-4.8	2.1	3.3	-8.8
LC	SSC(CSR) 84 L 01	0.0	0.0	0.0	0.0	-5.9	-2.6	-3.8
DM	SSC(DMA) 77 D 01	10.6	-69.7	-490.1	60.4	1.2	4.7	-813.7

The above parameters are to be used with equation (1), p. A-3.

↑
 A : optical astrometry
 D : satellite Doppler tracking
 L : satellite laser ranging
 M : Lunar Laser Ranging
 R : Radio Interferometry (CERI, VLBI)

This figure illustrates the key entries in the BIH 84 report

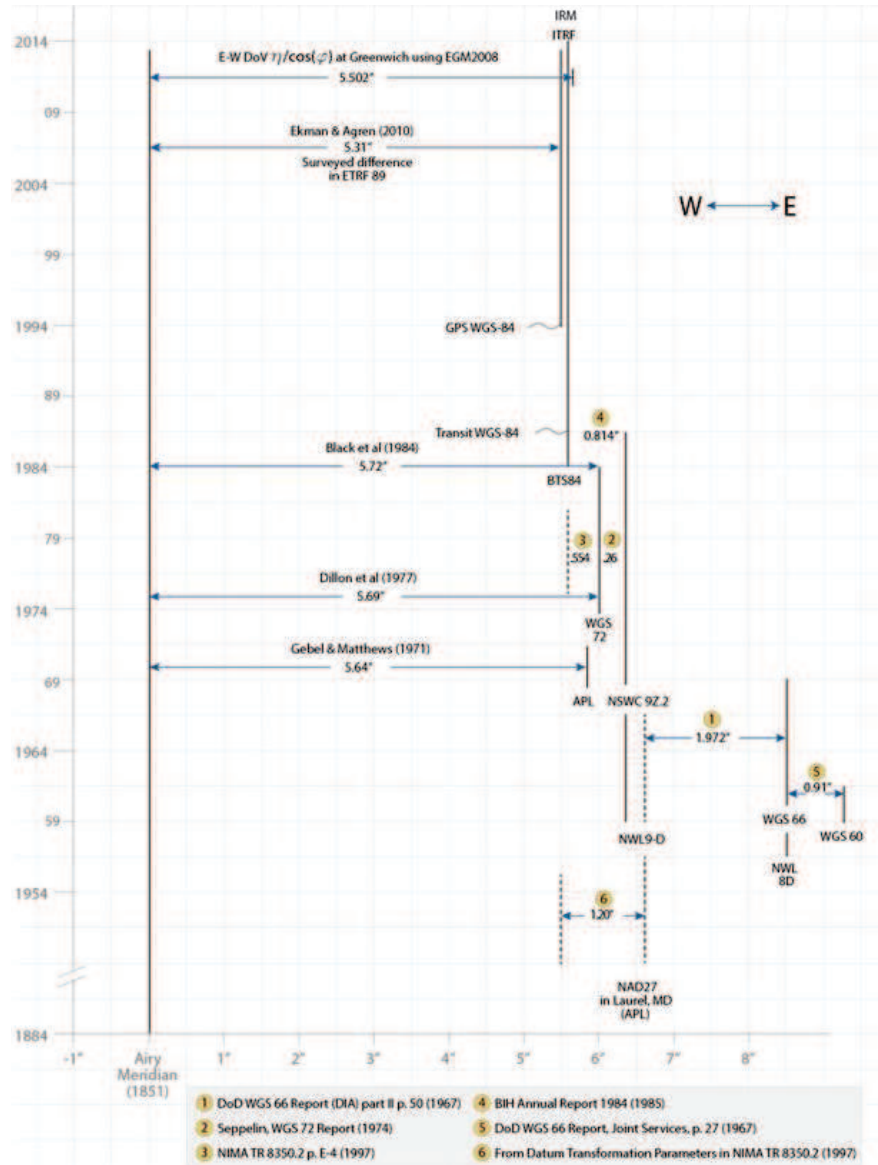


NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Know the Earth... Show the Way... Understand the World

Selected offsets among prime meridians from the “Space Age” and the Airy Transit Circle.

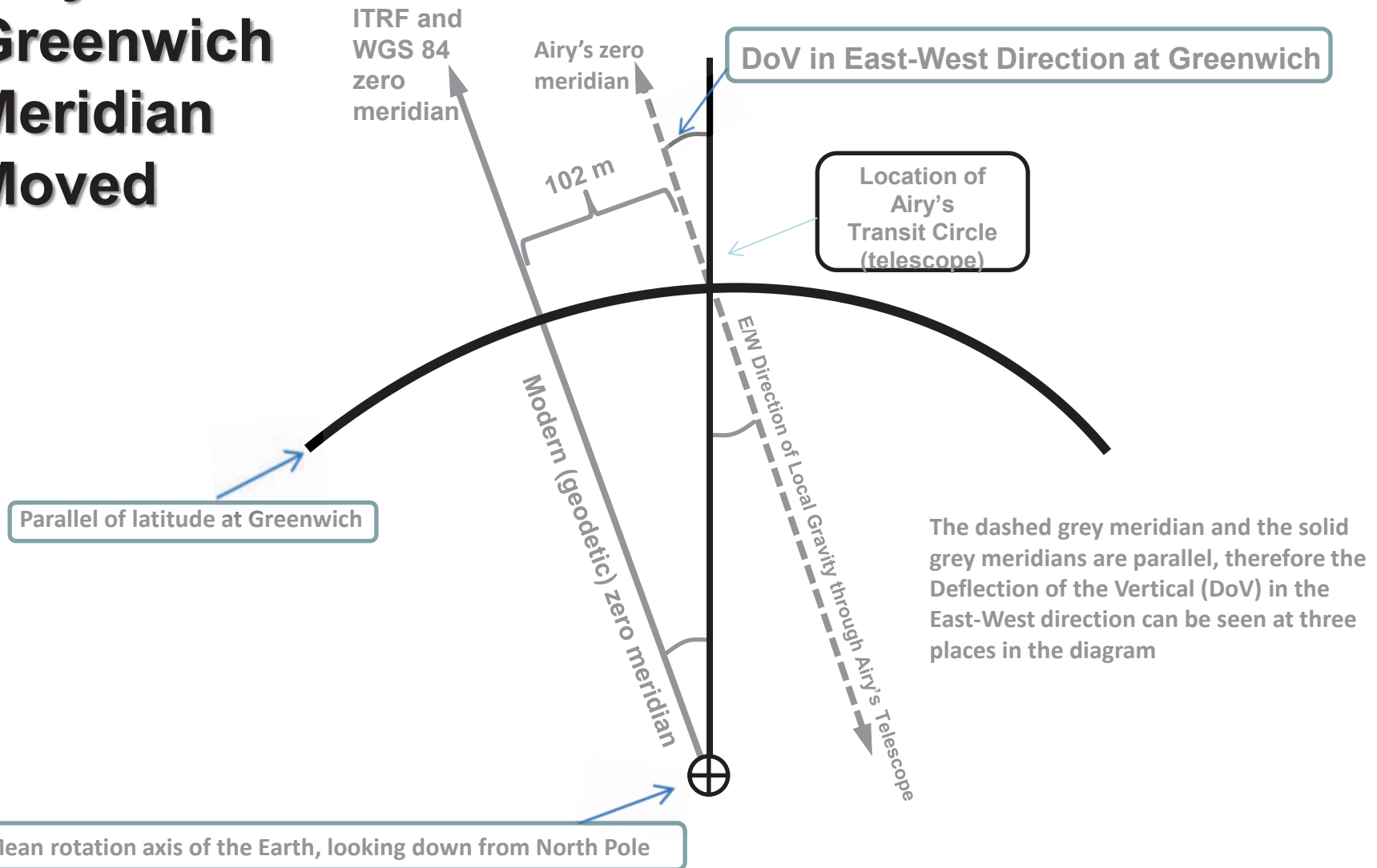
The yellow circle provides a reference for each documented offset





Why the Greenwich Meridian Moved

Orientation used to measure Universal Time (UT) remains the same





Other 'Conjectured' reasons

- TRANSIT did it
- Errors crept into the BIH process
- Greenwich functions moved to Herstmonceux in 1957
- Polar Motion
- Crustal motion (Plate Tectonics)
- Improvements in the fundamental celestial reference frame
- GPS did it



For an in-depth, peer-reviewed explanation see:

Why the Greenwich meridian moved by: Stephen Malys¹, John H. Seago², Nikolaos K. Pavlis¹, P. Kenneth Seidelmann³ & George H. Kaplan⁴. Journal of Geodesy

<http://link.springer.com/article/10.1007/s00190-015-0844-y>

¹ National Geospatial-Intelligence Agency, Springfield, VA

² Analytical Graphics, Inc., Exton, PA,

³ University of Virginia, Charlottesville, VA

⁴ United States Naval Observatory, Washington DC



NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Know the Earth... Show the Way... Understand the World

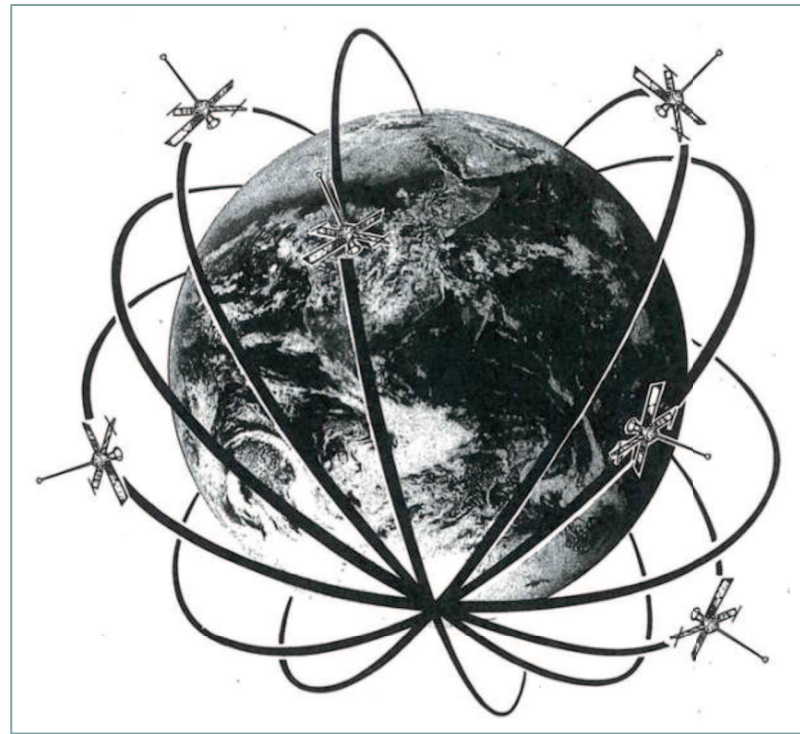
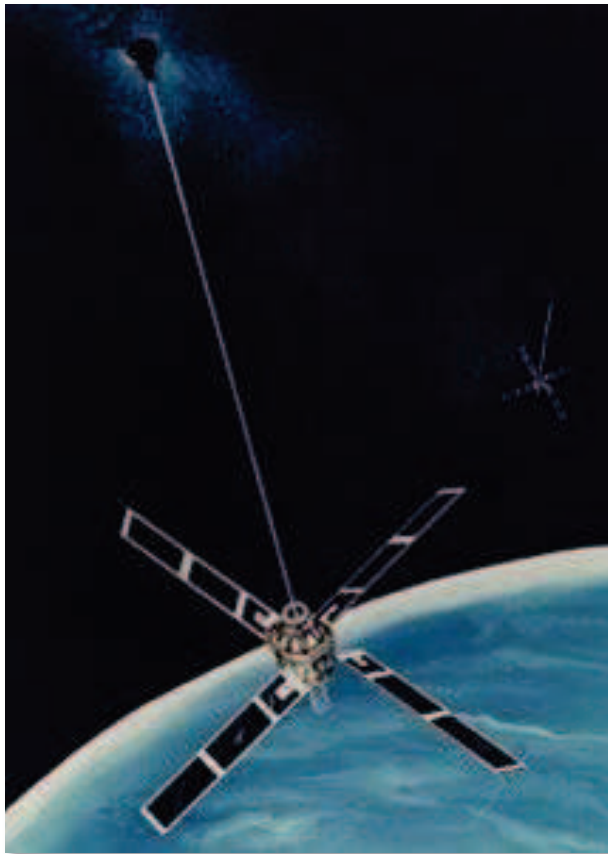
nga.mil | [@nga_geoint](https://twitter.com/nga_geoint) | facebook.com/natlgeointagency



Approved for public release 16-023



Navy Navigation Satellite System a.k.a. TRANSIT



Transit Satellites Form a “Birdcage” of Circular, Polar Orbits About 1075 km Above the Earth

Ref: The TRANSIT Navigation Satellite System, Thomas A. Stansell, Status, Theory, Performance, Applications, The Magnavox Government and Industrial Electronics Company, June, 1983



Early US Global *Geocentric* Earth Models

Need for these was driven by 'Long Range Missiles' & Defense-Related Satellites
 Most of these were 'Classified' at the time and only declassified in 1993

Name	Acronym	Methods	a (meters)	f
US Air Force 1958	USAF1958*	Gravimetric	6378270	1/297
US Air Force 1959	USAF1959	Gravimetric + f from Satellite Vanguard1958 β	6378185 +/- 50	1/298.3 +/- 0.1
US Army 1959	USA1959	Gravimetric + f from Satellite Vanguard1958 β	6378147 +/- 8	1/298.25
World Geodetic System 1960	WGS 60	Combination of earlier results	6378165	1/293
World Geodetic System 1966	WGS 66**	Gravimetric + TRANSIT, BE-B, BE-C, ANNA 1B, GEOS-A	6378145 +/- 20	1/298.25 +/- 2.2 X 10 ⁻⁷
World Geodetic System 1972	WGS 72	'Unified'	6378135 +/- 5	1/298.26 +/- 0.6 X 10 ⁻⁷

*a.k.a. USAF WGS 58, ** a.k.a. DoD WGS 66 and builds upon NWL-5, 5K, NWL-8, 8B, 8D, APL