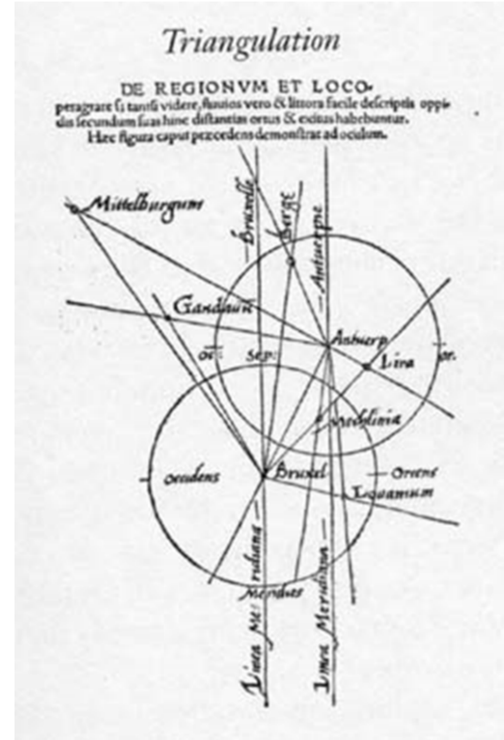
Geog 126: Maps in Science and Society

The rise of geodesy, satellites and GPS

The Figure of the Earth

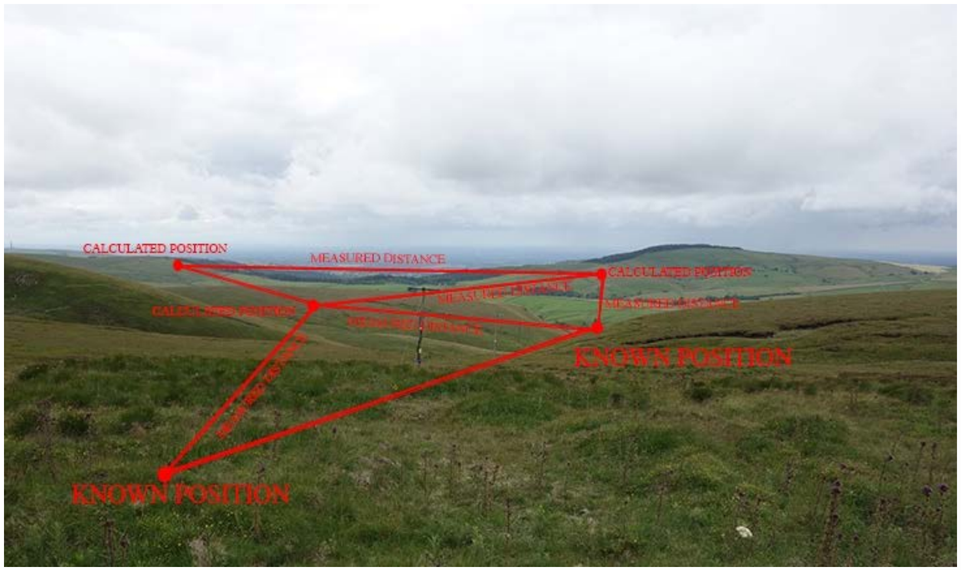
- Eratosthenes assumed Earth to be a sphere
- As triangulation for mapping began, measurements showed irregularities
- Multiple causes, but instruments too coarse to detect source
- Biggest anomaly was the actual shape
- Led to extraordinary experiments in measurement during the early 1700s

Gemma Frisius



- Dutch cartographer proposed using triangulation to accurately position far-away places for map-making in his 1533 pamphlet *Libellus de Locorum describendorum ratione* (Booklet concerning a way of describing places)
- Bound as an appendix in a new edition of Peter Apian's best-selling 1524 *Cosmographica*.

Triangulation spreads



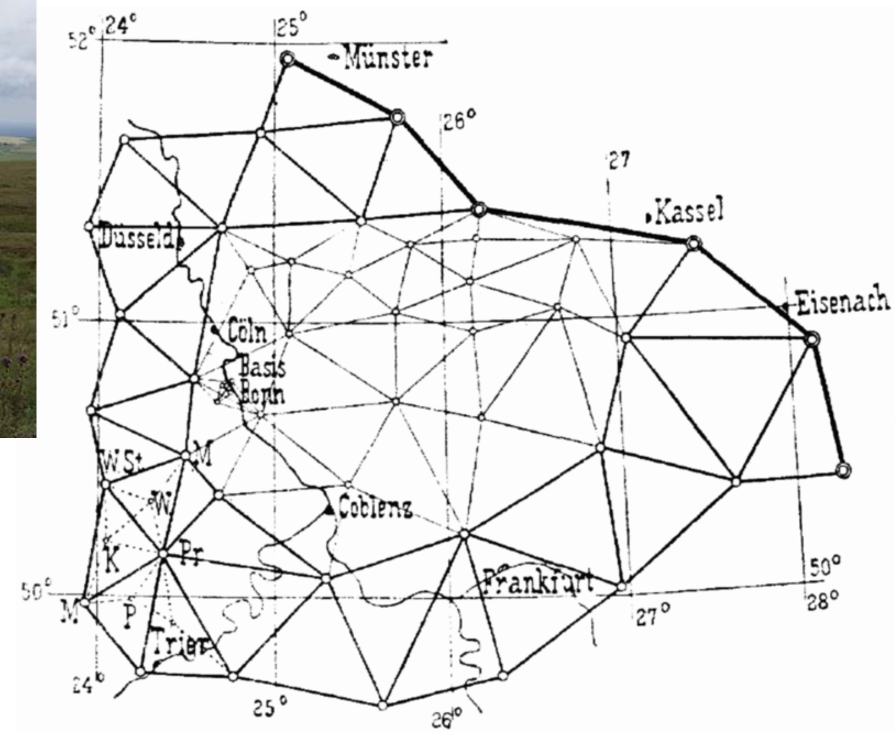
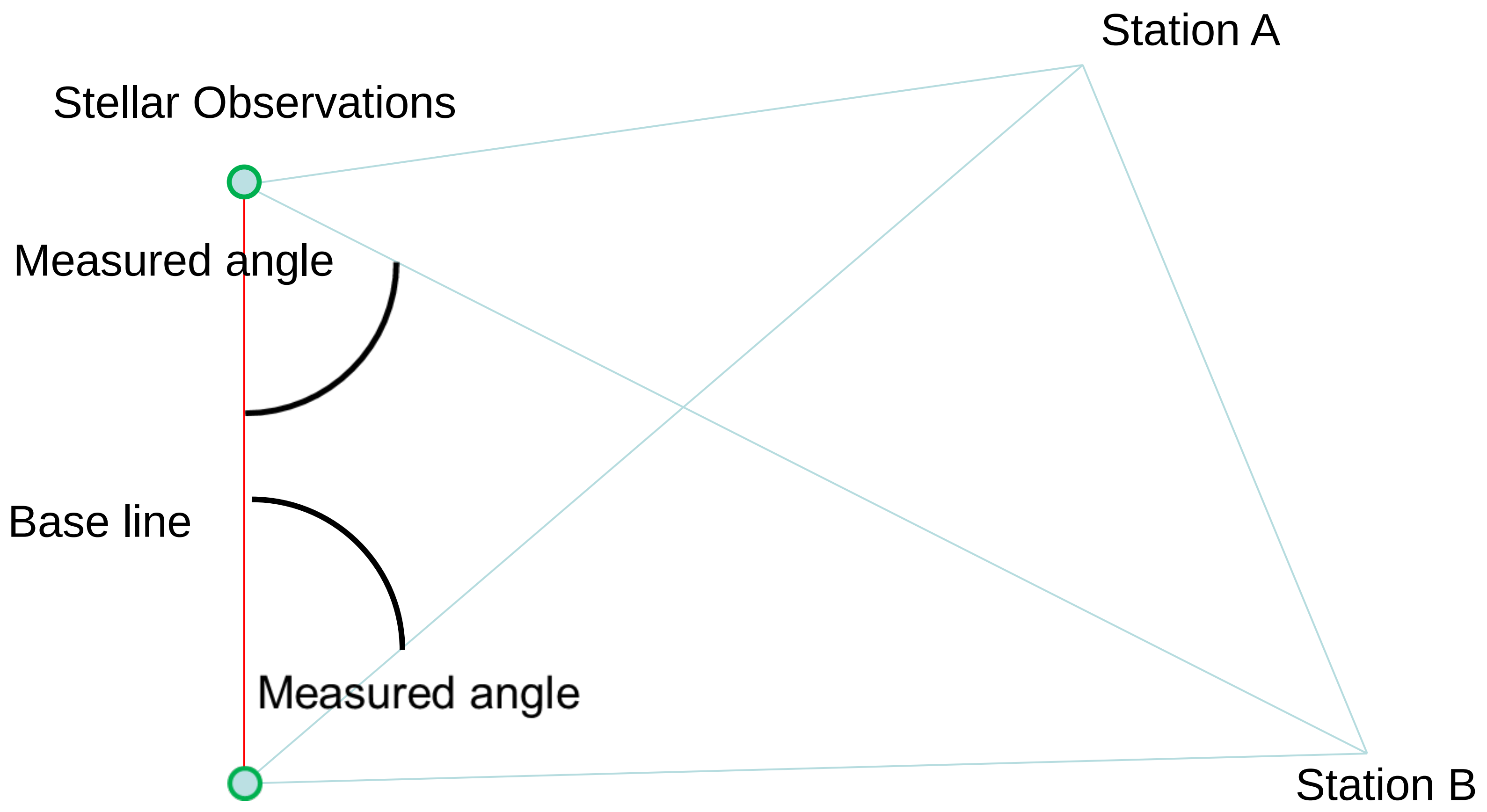


Fig. 4. Die rheinisch-hessische Kette und das niederrheinische Dreiecksnetz.

BUT: Two major issues
1) Length of a degree of lat vs. long
2) Earth not a sphere

Triangulation



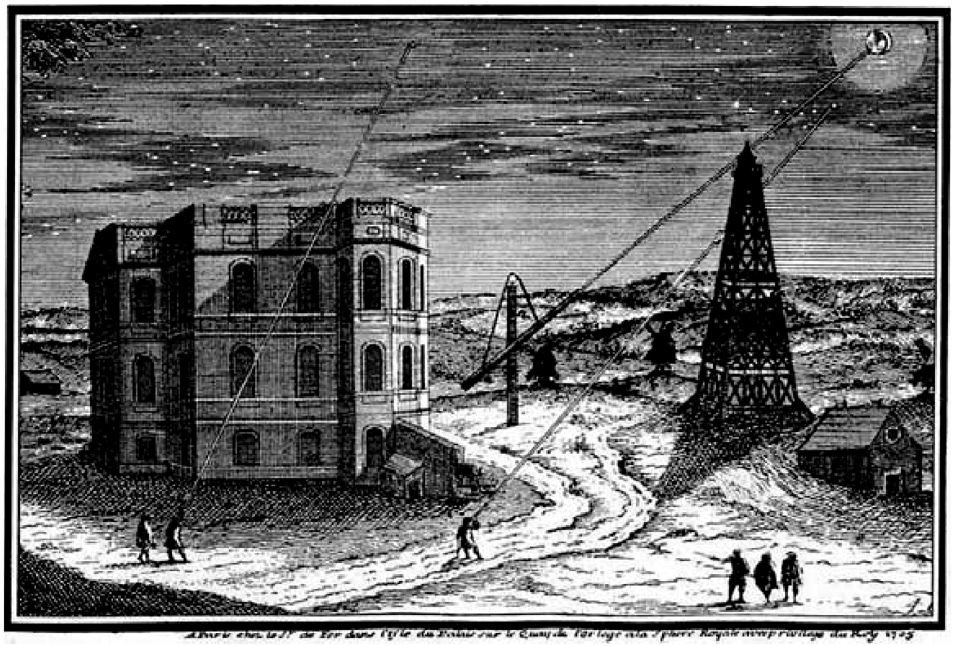
Context

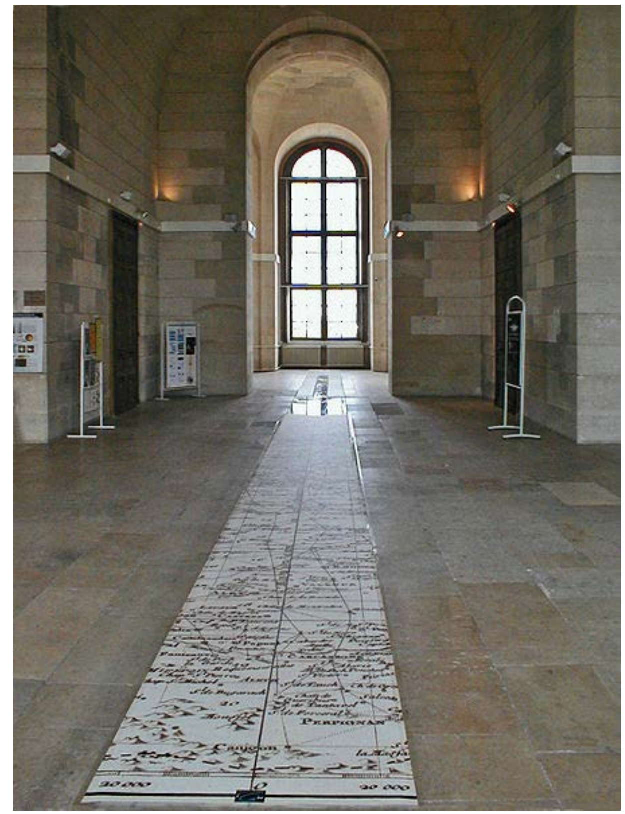
- Triangulation starts in the Netherlands, Germany, England
- Early measurements at Paris by the Cassinis
- Grand French triangulation under the Cassinis for the Paris meridian (1744) and the national map of France (1798-1812)
- Great trigonometrical survey of India
- Triangulations in the US lead to NAD27
- Major changes after WGS70

Geodesy begins

- Latitude can be accurately fixed using solar observation, origin at the poles and equator
- No origin for longitude
- Needed an established astronomical set of observations of stars and a link to time
- No common origin for longitude until 1884 (International Meridian Conference)

Paris, Royal Observatory completed 1671





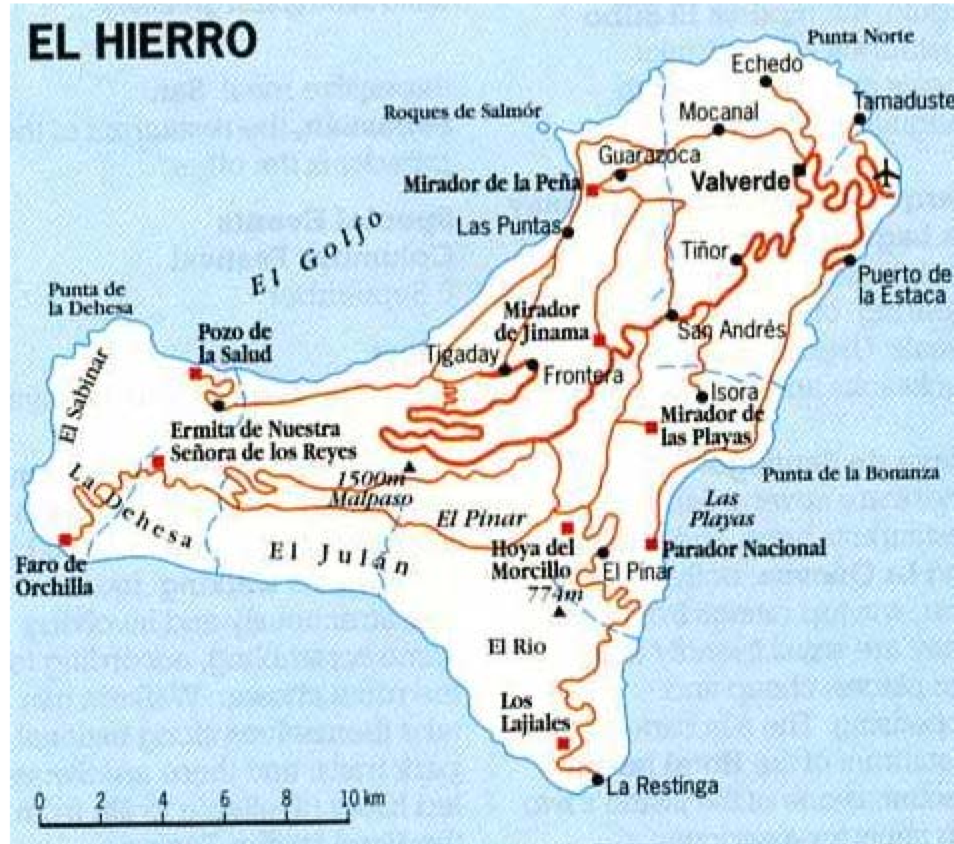
Giovanni Cassini (1671–1712)
Jacques Cassini (1712–1756)
César-François Cassini de Thury (1756–1784)
Dominique, comte de Cassini (1784–1793)

A note on prime meridians

- Ptolemy used Alexandria as prime
- Ulm Ptolemy starts numbering at African coast
- **El Hierro**, aka ***Isla del Meridiano*** , most westerly of the Canary Islands (27°45' N, 18°00' W)
- Later moved to Azores
- Important as the Line of Demarcation
- Also primes in London, Berlin, Paris, Bern, Washington D. C., Jerusalem, Lisbon, Madrid etc.
- Not standard until 1884, when Greenwich was chosen
- Adjustment made for IERS ITRF

Zero longitude

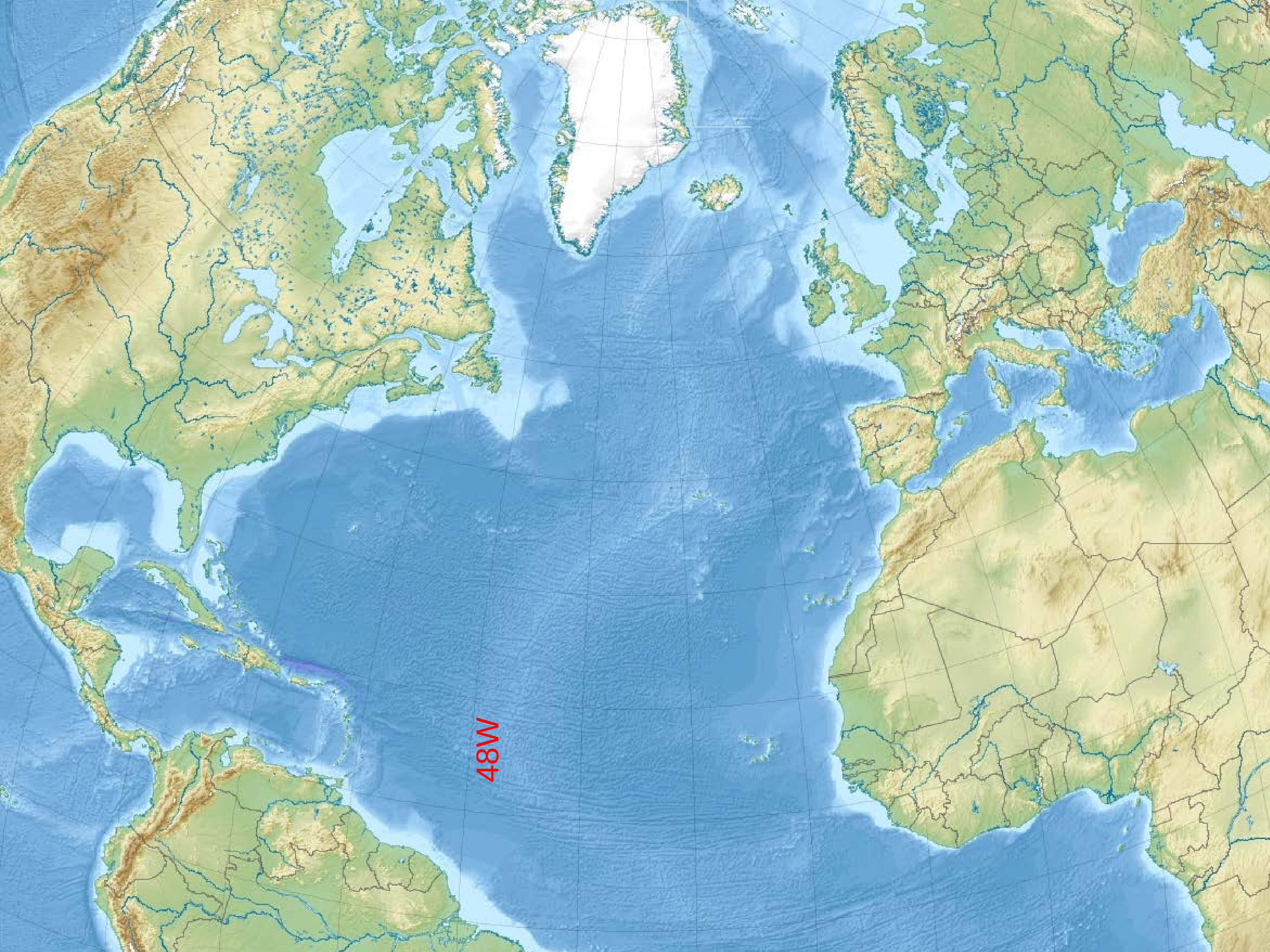
El Hierro, Canary Islands (Sp.)



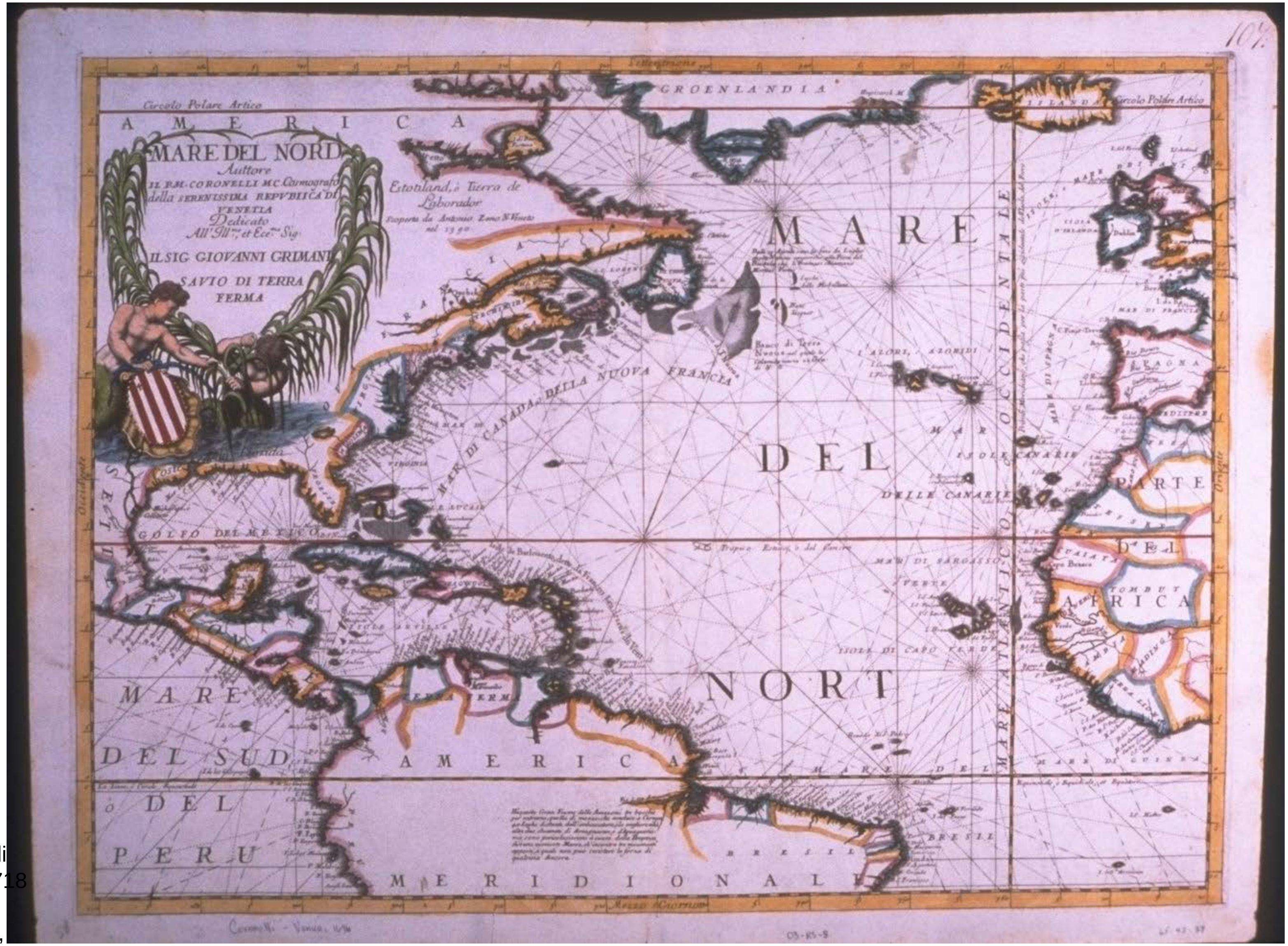
Mercator Atlas 1611: 4th Ed.

The Line of Demarcation

- Meridian chosen by Pope Alexander VI (1493) to divide America between Spain and Portugal
- Set precedent that European powers could divide new continents
- The line drawn ran north to south about 560 km west of the Canary islands.
- Portugal was allowed to claim land to the east of this line, and Spain to the west.
- The line was never surveyed and many historians suppose that it was near 48° W longitude.
- No nation was satisfied with this settlement, and a year later they mutually agreed by the Treaty of Tordesillas (signed in 1494) to shift the line 2,000 km (1,300 miles) to the west of the Cape Verde Islands.
- This later gave the Portuguese a claim to Brazil and the Philippines

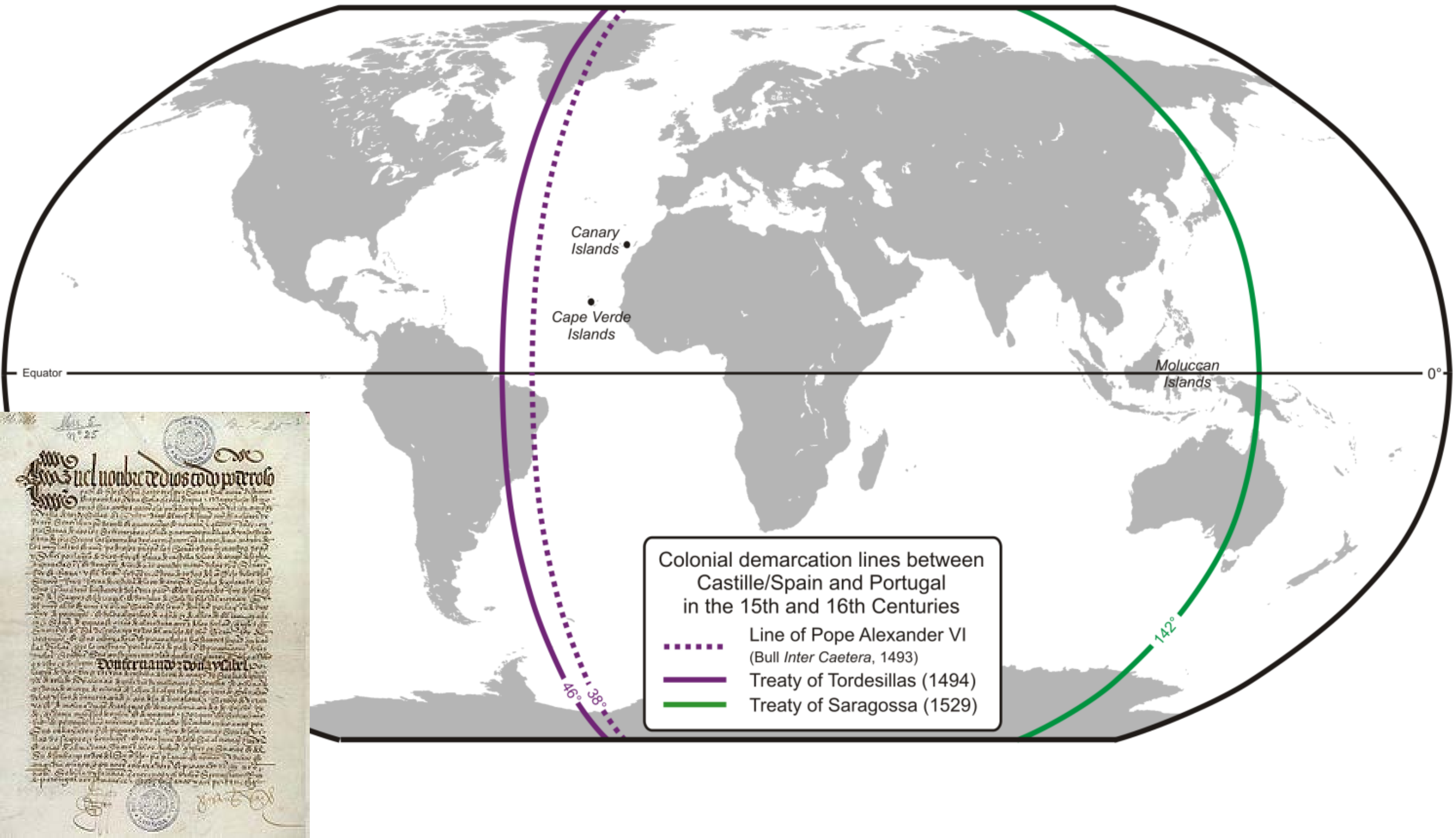

48W

Cape Verde/Azores meridian

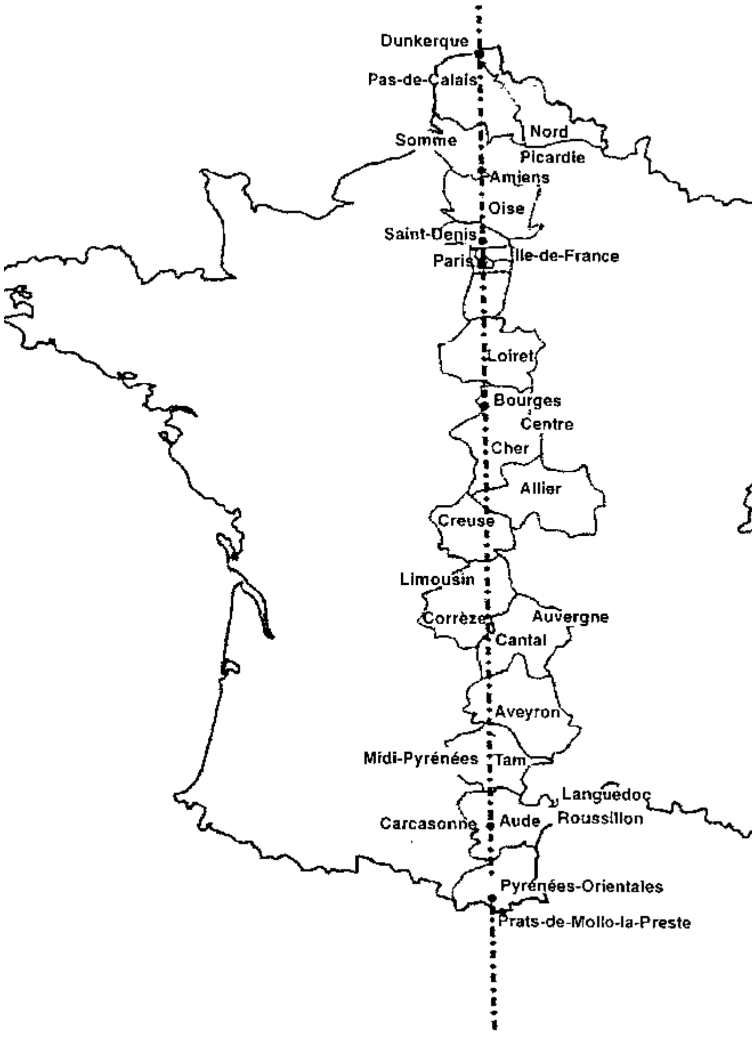


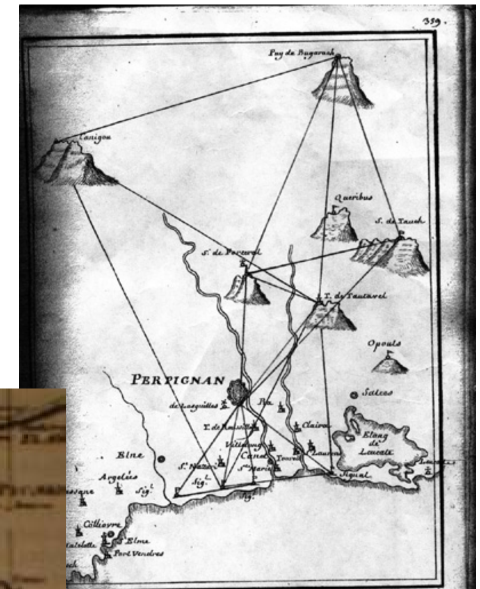
Vincenzo Coronelli
Venetian, 1650-1718
Mare Del Nord
Copper engraving,
hand-colored, 44.9cm x 59.9cm
Venice, 1690

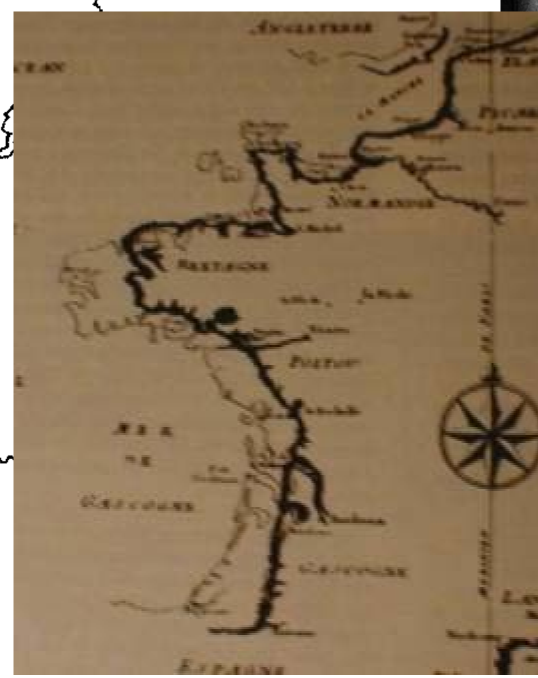
Treaty of Tordesillas



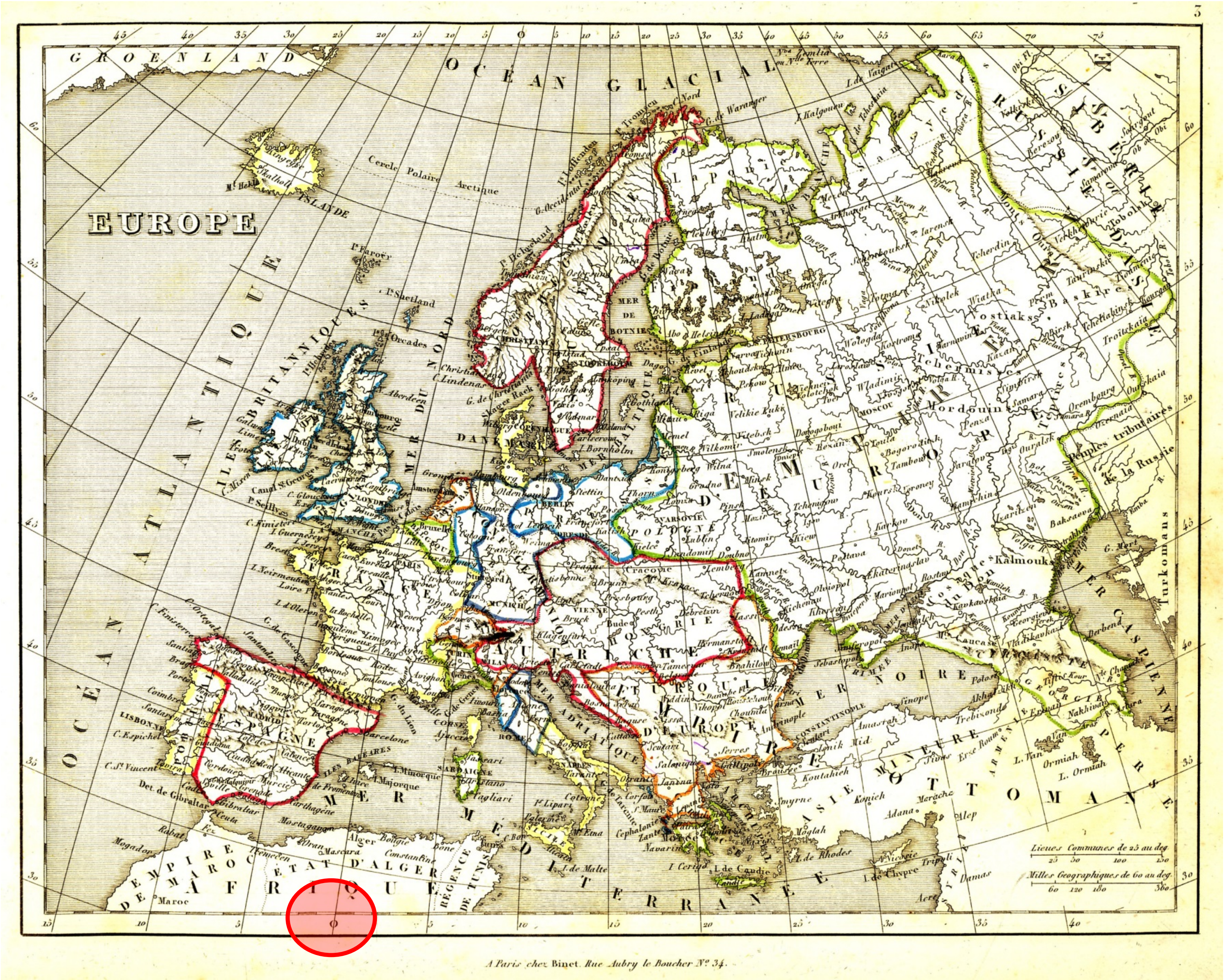
Cassini: The Paris meridian







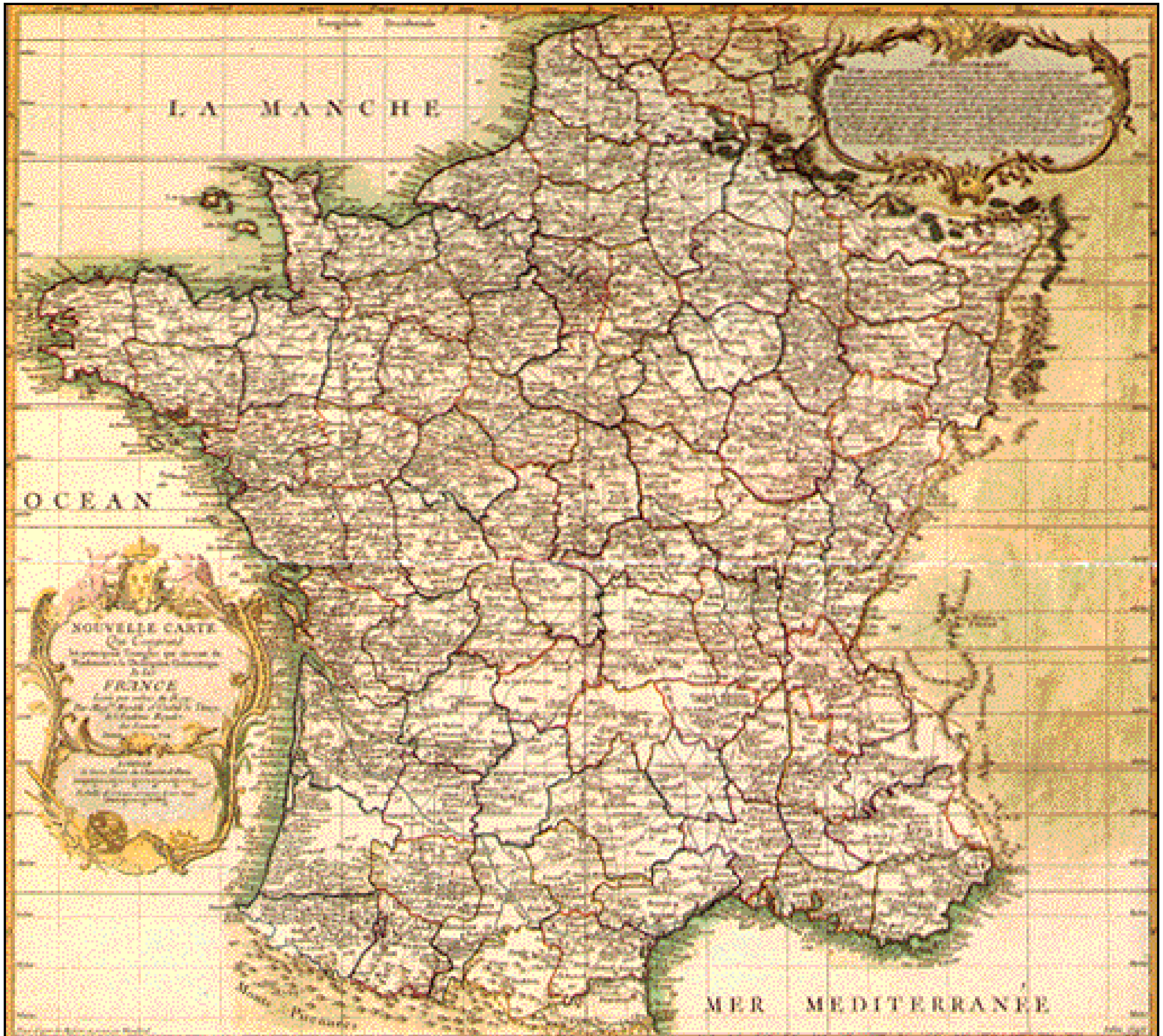
From: Atlas Universel des Cinq Parties du Monde, dressé par Messrs. C.V. Monin & A.R. Fremin, Gravé par Benard. Paris, chez Binet, 1836. 195 x 250 mm.



The Cassinis

- 1672 Jean Dominique Cassini, (Cassini I) Royal Astronomer of the Paris Observatory, began to consider new ways to produce more accurate maps through triangulation, to locate observatories
- Make first critical triangulations around the Paris observatory, establishing the Paris meridian
- With Jacques Cassini (Cassini II) produced the first accurate survey of an entire nation, in 1744
- In 1747 Louis XV asked Ceasar-Francois Cassini (Cassini III) to create an even more precise national map of France, completed by his son Jacques Dominique Cassini (Cassini IV)
- 180 maps covering all of France at a scale of 1:86,400. These 180 'cartes de l'Academie' published from 1798 through 1812.

1744 Map of France based on triangulation surveys by Jacques Philippe Maraldi and Cesar Francois Cassini de Thury.

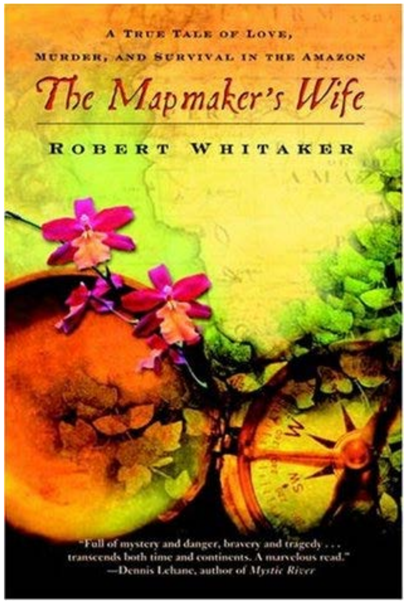


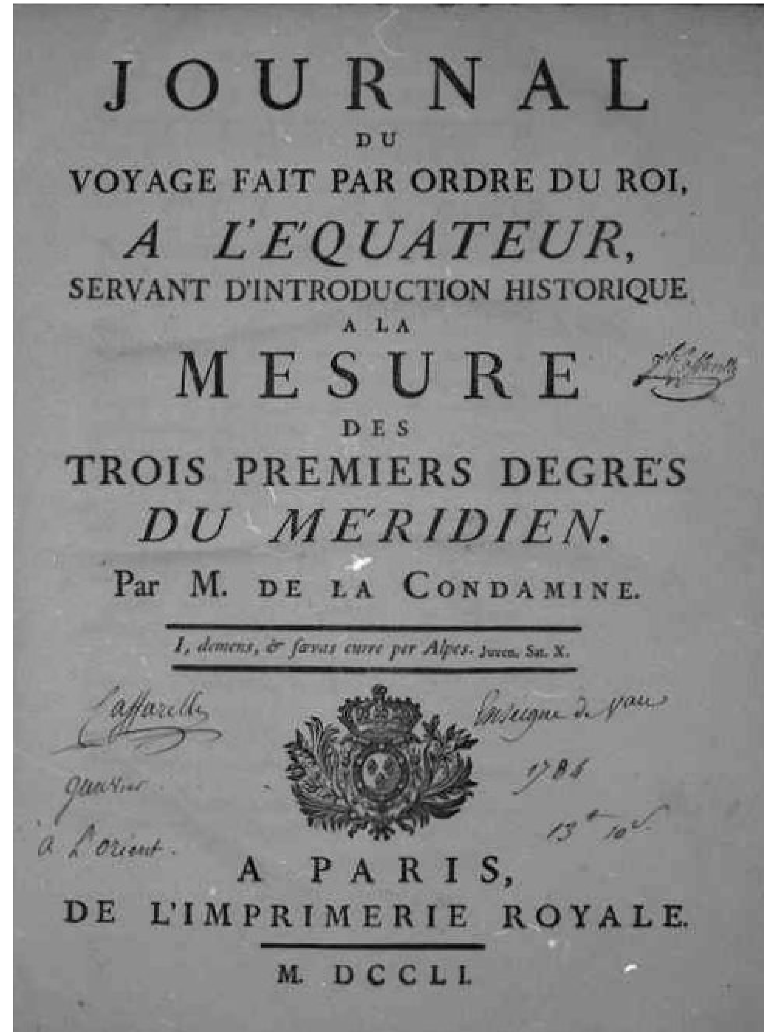
Cassini Map of France 1798-1812

The Figure of the Earth

- *1730s Académie des sciences* debate of the shape of the earth
- French astronomer Jacques Cassini held to the view that the polar circumference was greater.
- Louis XV, the King of France and the Academy sent two expeditions to determine the answer
- One was sent to Lapland, under Swedish physicist Anders Celsius and French mathematician Pierre Maupertuis.
- The other mission was sent to Ecuador (Peru), at the Equator, led by Godin, included Bouguer and LaCondamine
- Previous accurate measurements had been taken in Paris by Cassini and others.

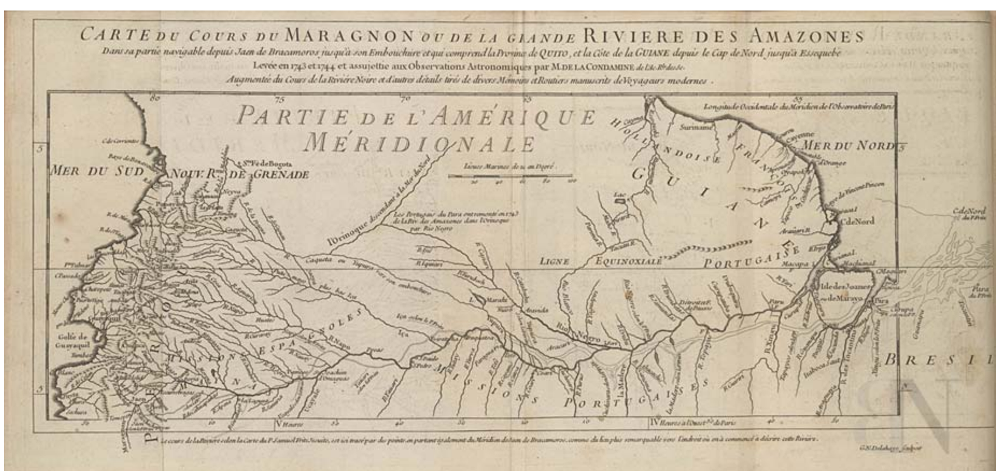
Charles Marie de la Condamine



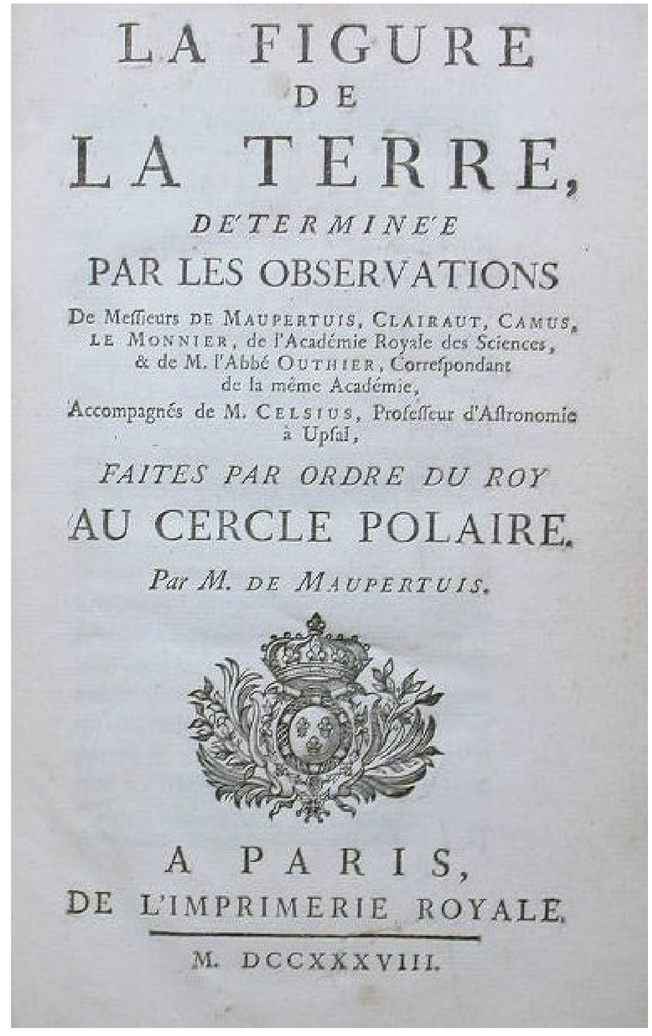

JOURNAL
DU
VOYAGE FAIT PAR ORDRE DU ROI,
A L'EQUATEUR,
SERVANT D'INTRODUCTION HISTORIQUE
A LA
MESURE
DES
TROIS PREMIERS DEGRÉS
DU MÉRIDIEN.
Par M. DE LA CONDAMINE.

I, demens, & sævas curre per Alpes. Juven. Sat. X.

A PARIS,
DE L'IMPRIMERIE ROYALE.
M. DCCLI.



Pierre-Louis Moreau de MAUPERTUIS (1698-1759)

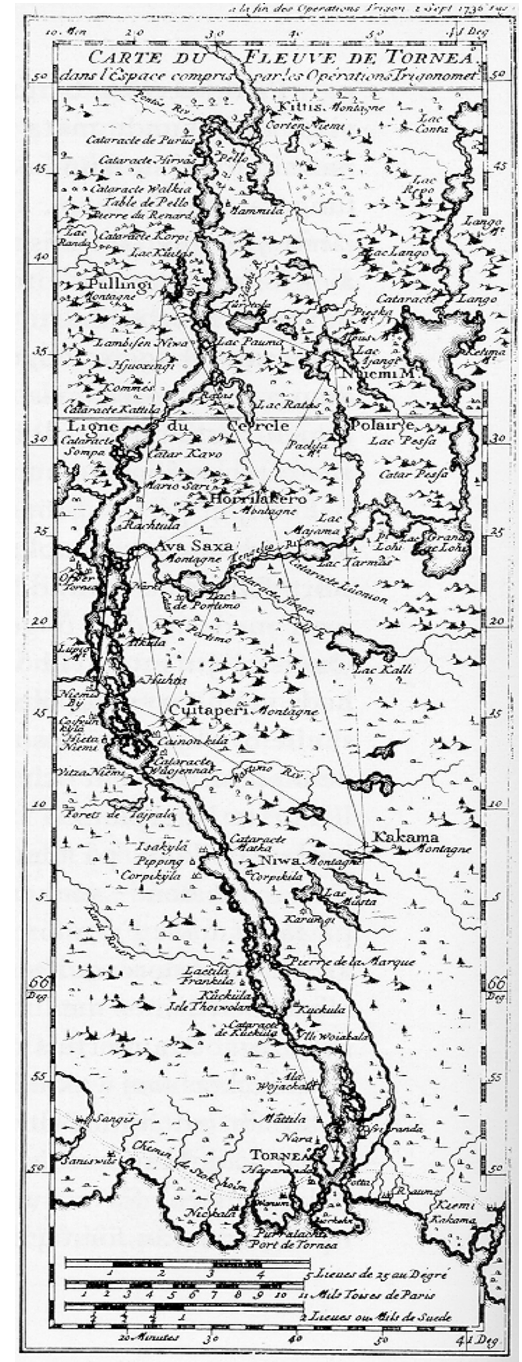


LA FIGURE
DE
LA TERRE,
DÉTERMINÉE
PAR LES OBSERVATIONS
De Meſſieurs DE MAUPERTUIS, CLAIRAUT, CAMUS, LE MONNIER, de l'Académie Royale des Sciences, & de M. l'Abbé OUTHIER, Correſpondant de la même Académie,
Accompagnés de M. CELSIUS, Profeſſeur d'Aſtronomie à Upſal,
FAITES PAR ORDRE DU ROY
AU CERCLE POLAIRE.
Par M. DE MAUPERTUIS.

A PARIS,
DE L'IMPRIMERIE ROYALE.
M. DCCXXXVIII.

Maupertuis's Map

- River Tornio in modern Finland
- 14.3 km base line laid out on the ice



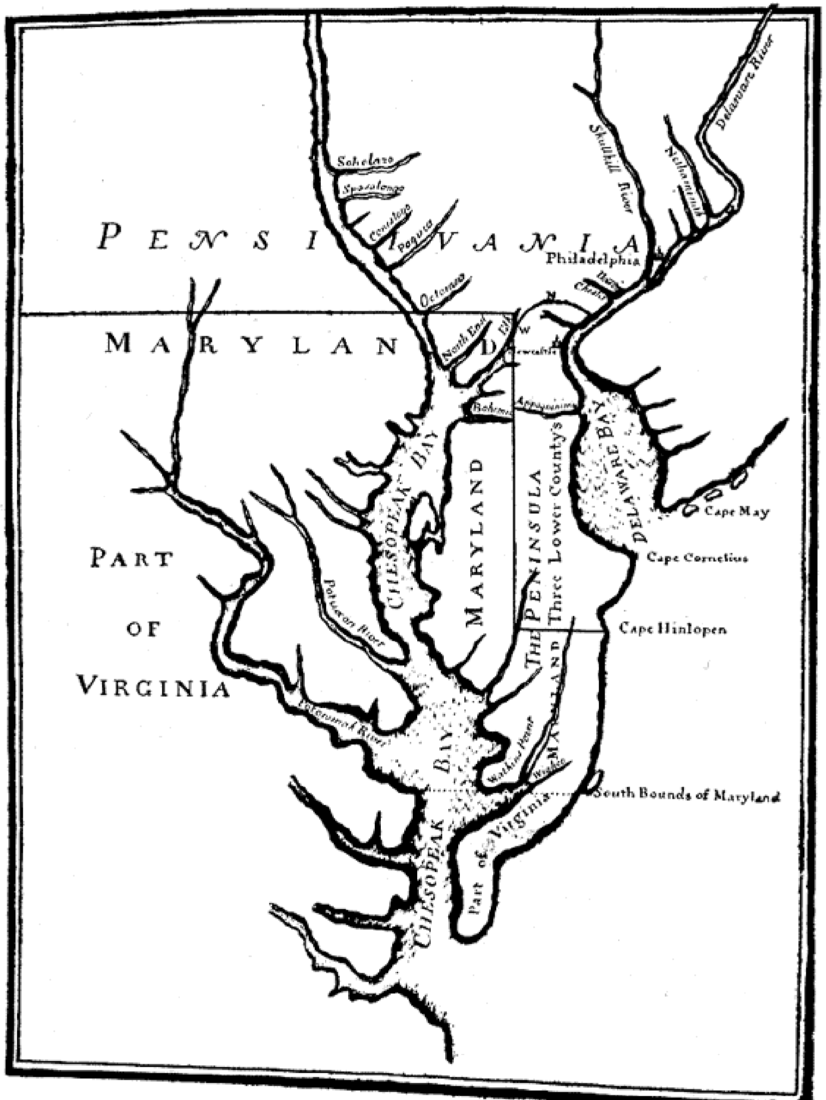
Measuring the Ellipsoid

- Maupertuis reported a meridian degree as 57,437.9 toises (1 toise = 1.949 m)
- Meridian degree at Paris was 57,060 toises
- Concluded Earth was flatter at poles
- Measures were erroneous but conclusions were correct
- Published as "La Figure de la Terre" (1738)

Back to geodesy

- Degree of earth’s ellipsoidal distortion a critical scientific issue
- Resolved by Maupertuis’ measure compared to Cassini’s, reinforced by La Condamine’s result
- But measurements continued
- E.g. Southward extension of the Mason-Dixon line an attempt to measure a degree in the Americas

Mason-Dixon line

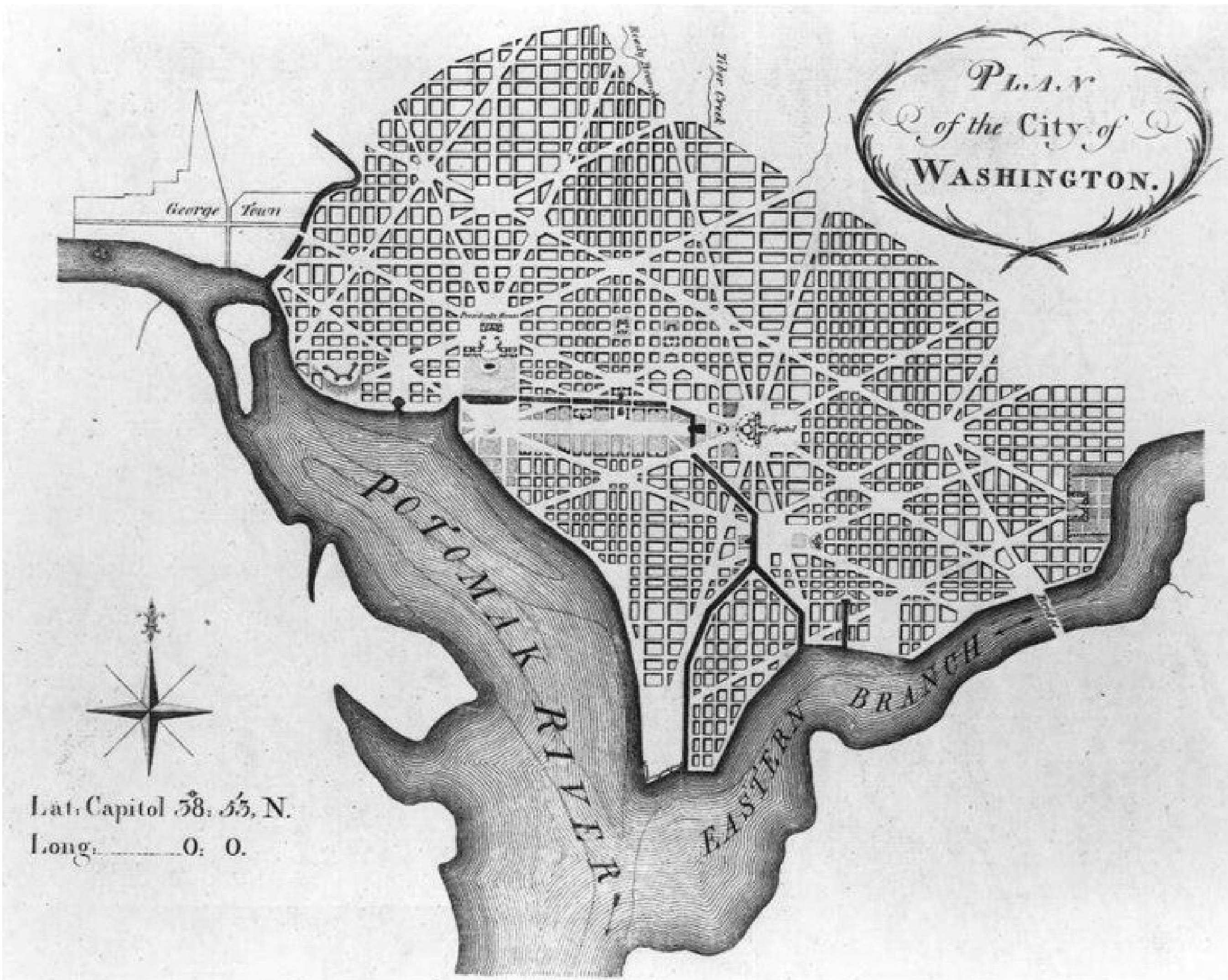


Completed 1767

Meridional arc measurements during the 18th and 19th centuries

Length of a degree (km)	Year	Observer	Country	Latitude of Middle arc (Deg/Sec)
111.49	1738	Maupertius - re-examined by Svanberg	Lapland	1.31.08 N
111.23	1802	Roy & Kater	England	52.35.45 N
111.11	1790	Delambre & Mecham	France	44.51.2 N
111.03	1755	Ruscovich	Rome	42.59.0 N
110.87	1750	Abb Lacaille	Cape of Good Hope	33.18.30 S
110.66	1835	Everest	India	16.7.22 N
110.64	1808	Lambton	India	2.32.21 N
110.58	1735	Condamine & Bouguer	Peru	1.31.08 N

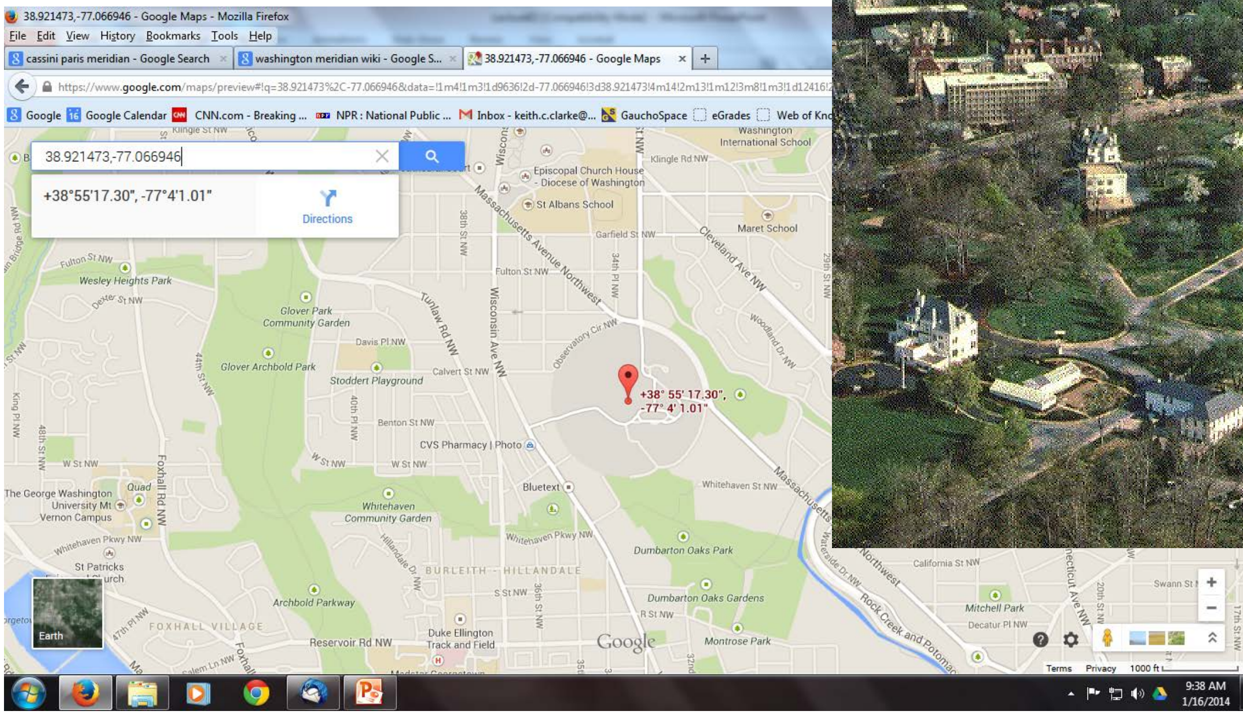
Washington Meridian at N. Capitol St: Old map of Washington DC, March 1792 by Thackara and Vallance, Philadelphia, Geography and Map Division, Library of Congress.

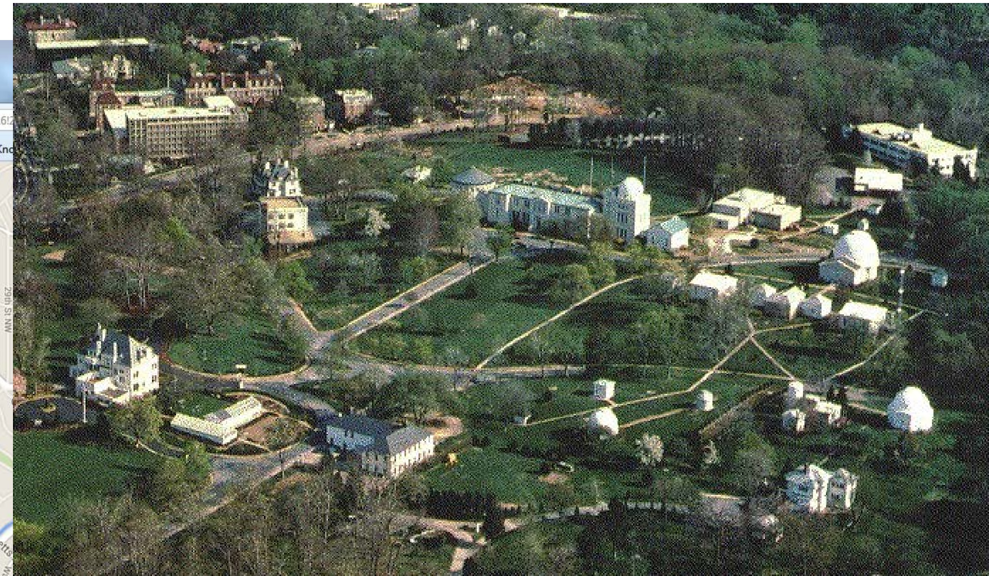


Four meridians

See: https://www.youtube.com/watch?v=LVEDJEzzogg

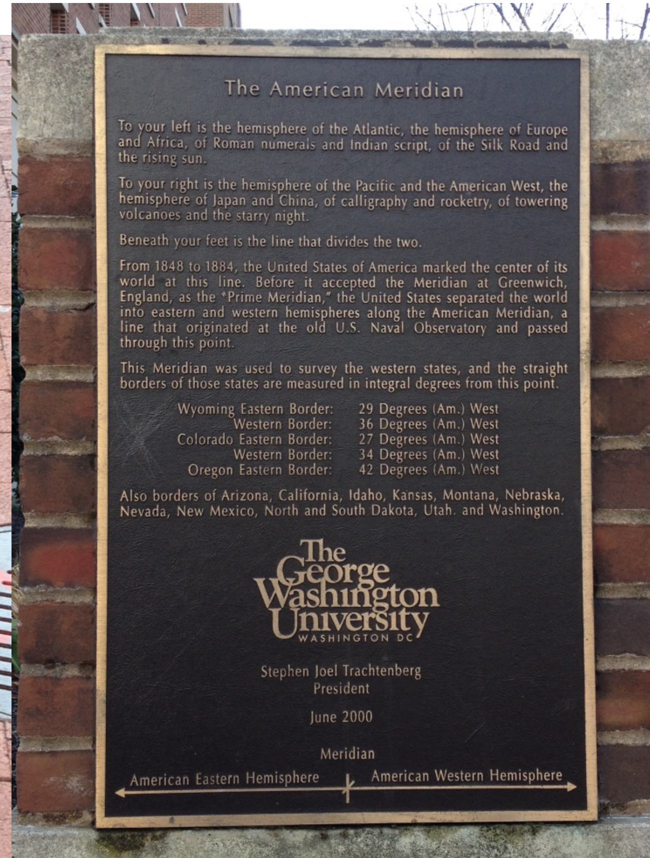
Finally, 1898-1950!





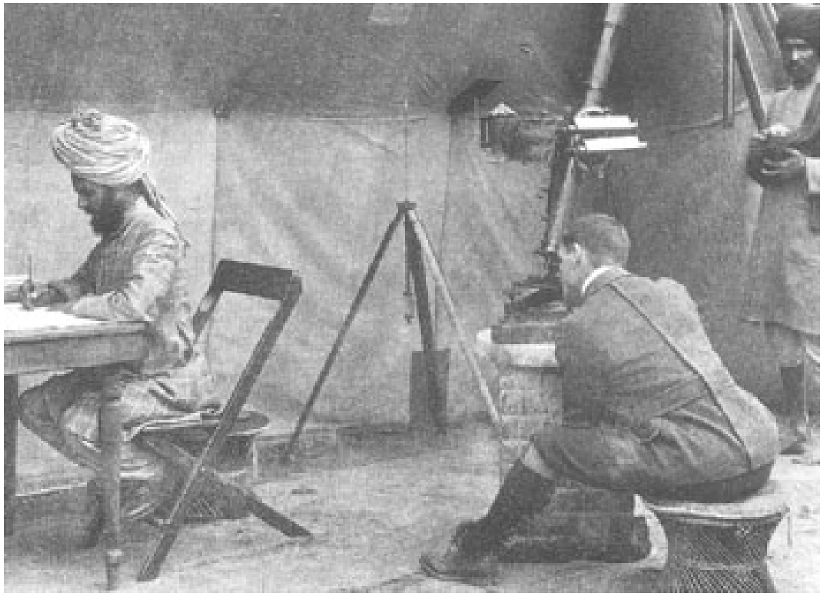
Through the exact center of the clock room of the new Naval Observatory 3.8 km northwest of the White House, at 77°3'56.7"W (1897) or 77°4'2.24"W (NAD 27) or 77°4'1.16"W (NAD 83).

Washington Meridians



Establishing an Arc

- Set up triangulation stations in visible locations
- Make observations of horizontal and vertical angles
- Lay out baseline on flat terrain, link to triangulation
- Complete with solar, lunar and moons-of-Saturn observations at arc ends



India Great Arcs

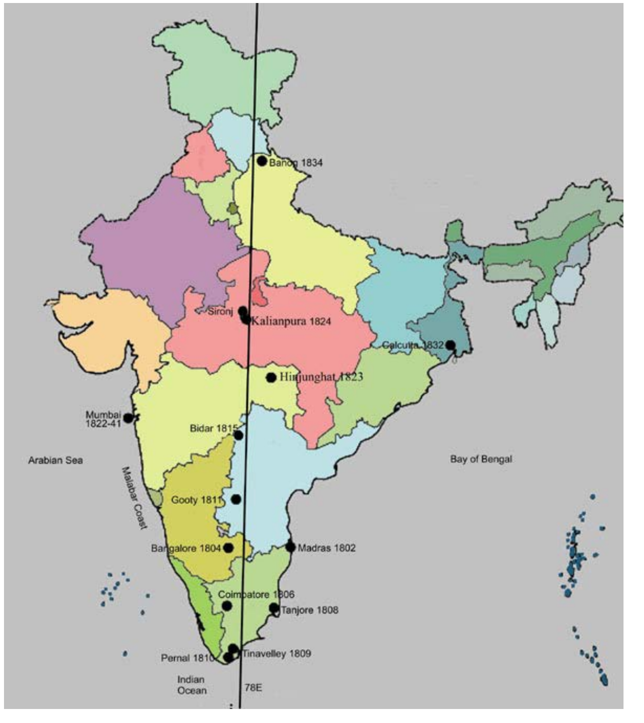
- East India Company dominates India from1757 and lasted until 1858, with a standing private army of 260,000
- 1784 Alexander Dalrymple suggested a triangulation along the eastern coast of India.
- Michael Topping was appointed Marine Surveyor in 1791, an advocate of triangulation
- 1799, Col. William Lambton proposes a plan for a Mathematical and Geographical Survey right across the subcontinent
- Survey starts10 April 1802, with the measurement of a 12.8 km base line on a flat plain near Madras

The Great Arc of India

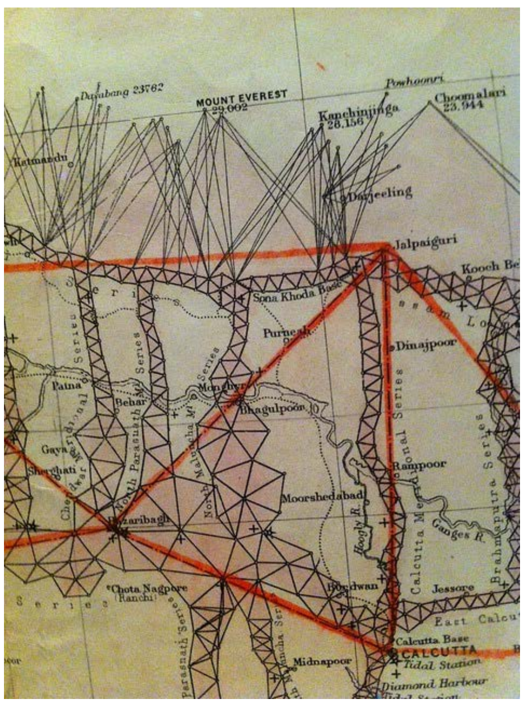
- Initiative was the measurement of an arc of meridian (78 deg. E) from Tirunelveli (Tinnevelly), at the southern tip of India, to Banog, in the foothills of the Himalayas
- Also important for a base

map of the continent, and

for colonial rule



Tirunelveli to Banog

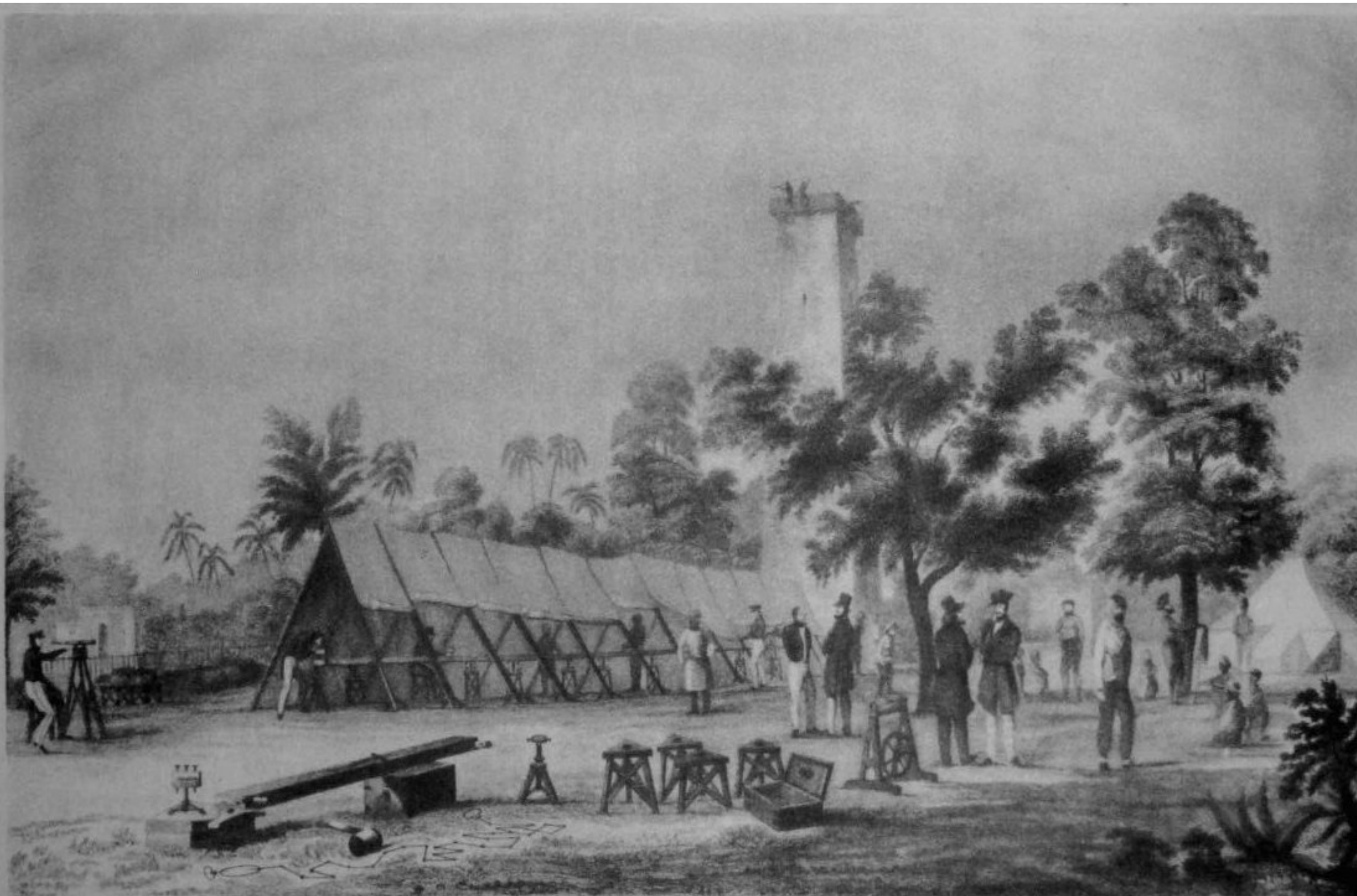


Great Trigonometrical Survey of India

Ramsden Theodolite

William Lambton

Kolkata (Calcutta) Base Line



CALCUTTA BASE LINE

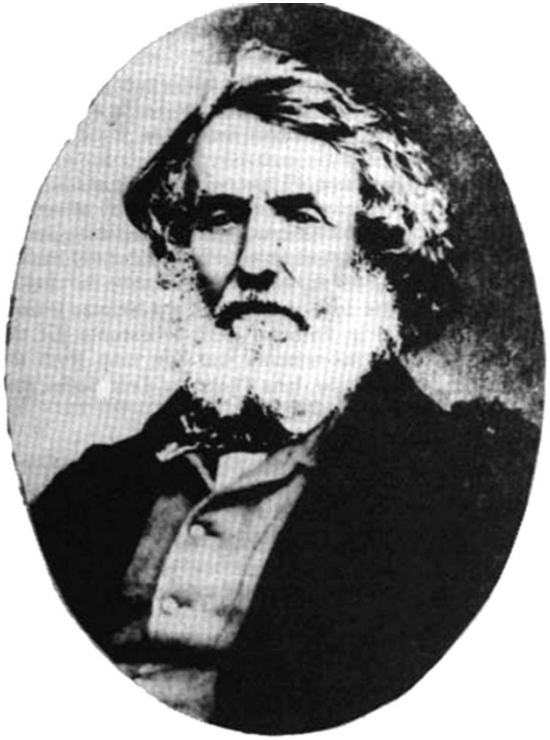
from a sketch by James Prinsep, Jany. 1832
[III, 495 ; IV, ch. iv].

Reg. No. 5521 HD'52-800'54

Printed at the Survey of India Offices (H.L.O.).

Filling in the map

- 1815, Lambton measured another baseline near Bidar, at a station called Dumargidala
- 1818, George Everest joined Lambton
- 1822, Lambton continued the survey from Hyderabad towards Nagpur
- Lambton died on the road at Hinjunghat on 20 January 1823



Survey gets renamed

- After Governor general took control of survey, it was renamed the Great Trigonometric Survey
- After Lambton's death, Everest assumed control
- Tropic of Cancer reached in May 1824
- Everest completed the astronomical observations at Kalianpura in November 1824


INDIA

Finishing the survey

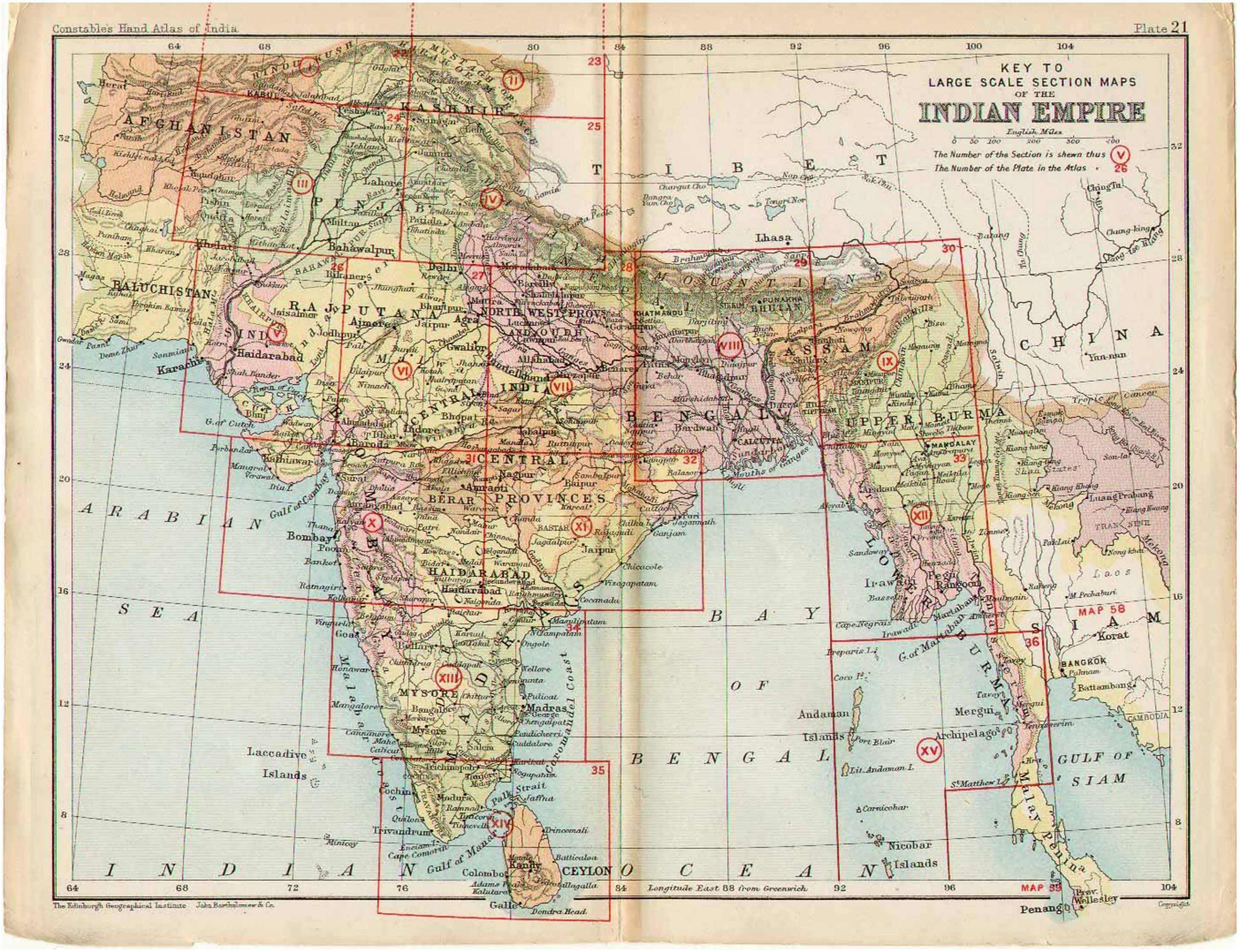
- Longitudinal series of triangles (1120 km) completed July 1832
- Masonry towers 20-30 m high
- Ray tracing methods used for locating the stations
- Introduced the grid iron system of triangulation coverage
- Major baselines connected in February 1837
- When base lines were connected, positional error was only 183 mm.
- Great Trigonometrical survey completed in 1866
- Himalayan peaks included, Mt. Everest, K2

Up to the Himalaya (Kangchenjunga)

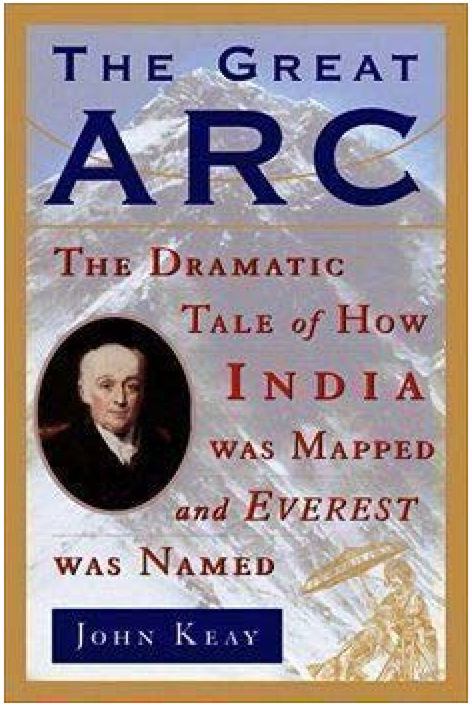
Conflicting goals and needs

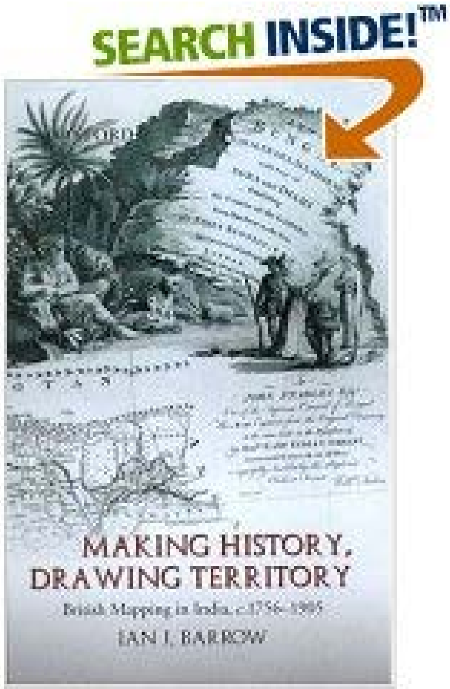
- Geodetic measurement and national mapping needs often in conflict
- Almost all topographical and cadastral surveys in India were undertaken before the general triangulation could reach them
- Local surveys had anchored to inconsistent reference points
- British survey activities intended to be unified in 1878 by the formation of the Survey of India, of which the GTS became the Geodetic Branch
- 1820 Atlas of India at 1:253,440

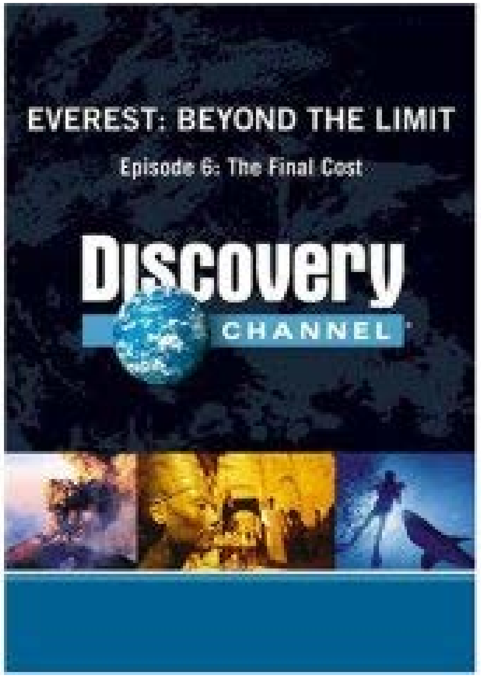
1820 Atlas sheet index



Much study


THE GREAT
ARC
THE DRAMATIC
TALE of HOW
INDIA
WAS MAPPED
and EVEREST
WAS NAMED
JOHN KEAY

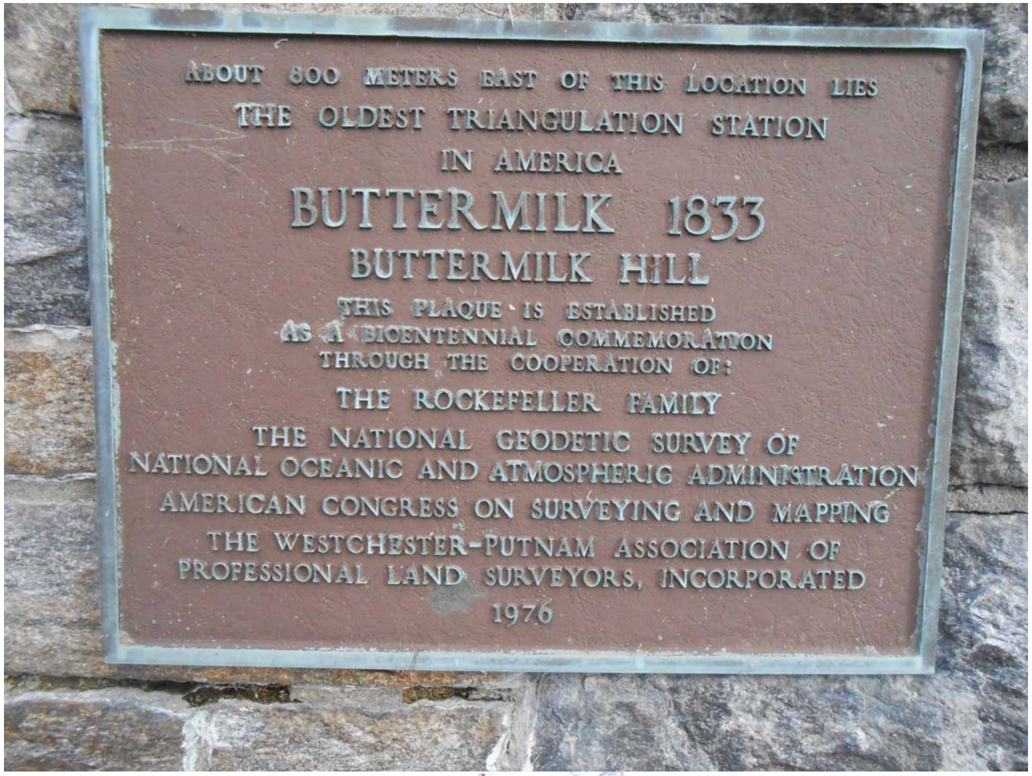

SEARCH INSIDE!™
MAKING HISTORY,
DRAWING TERRITORY
British Mapping in India, c.1756–1905
IAN J. BARROW

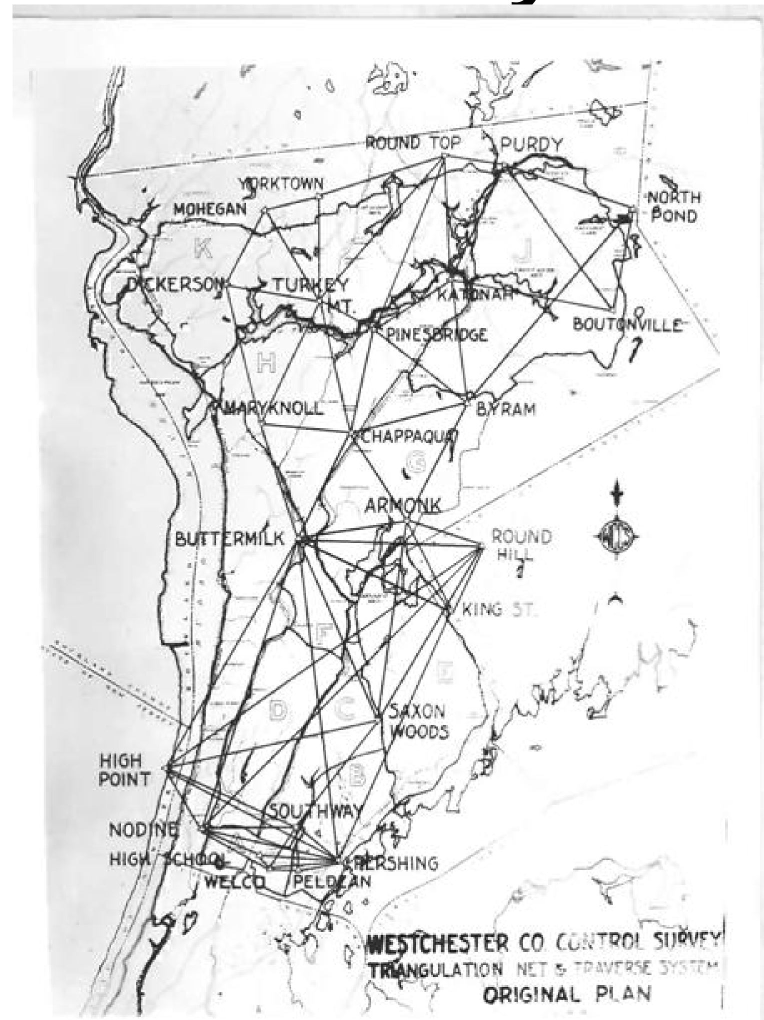

EVEREST: BEYOND THE LIMIT
Episode 6: The Final Cost
Discovery
CHANNEL

US Surveying Bilby Towers

STATION TENSAS - 159 ft.
Pfau, Chief of Party.
Atlanta-Shreveport Arc.
April, 1931.

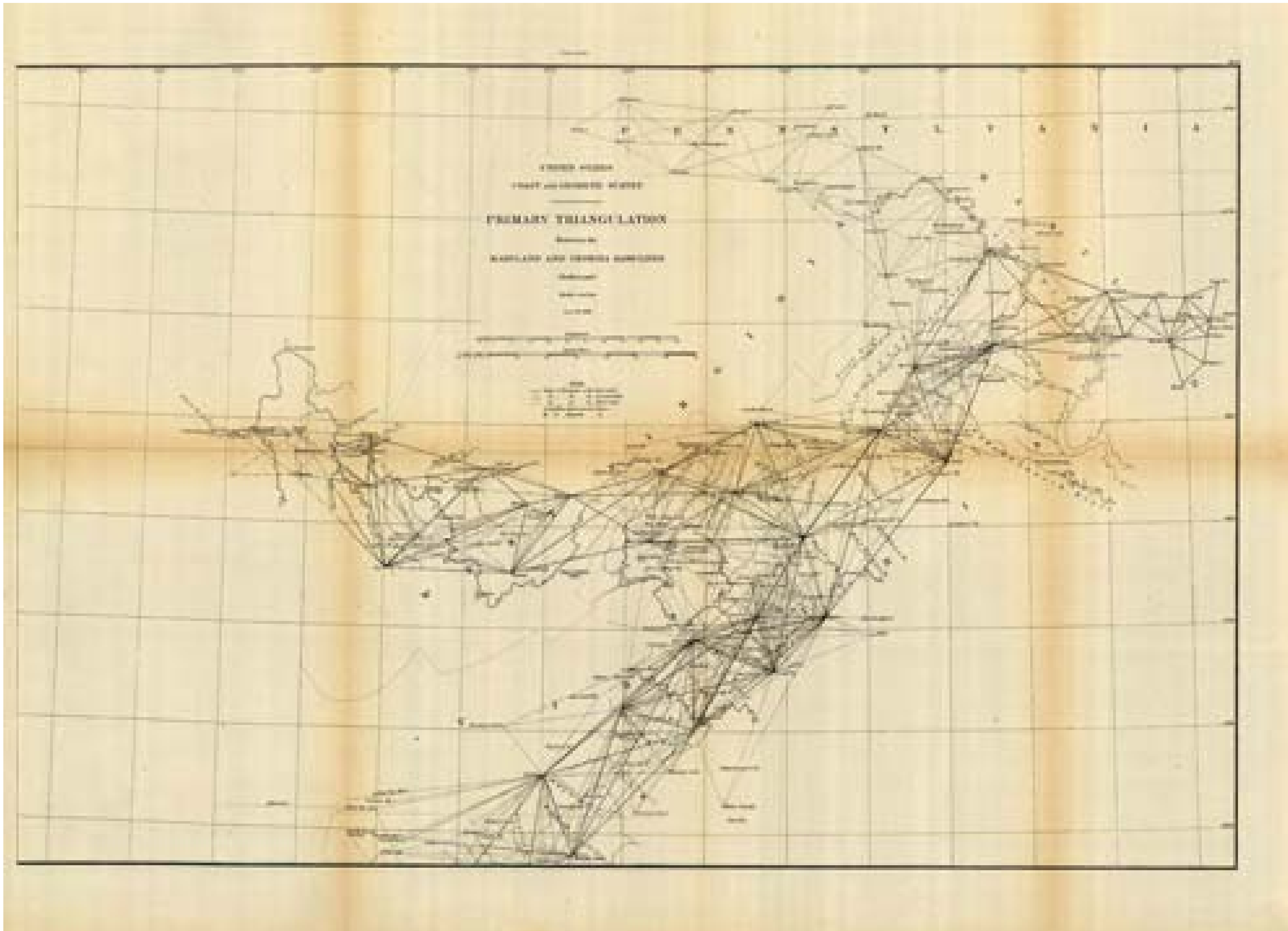
Triangulation and local surveys





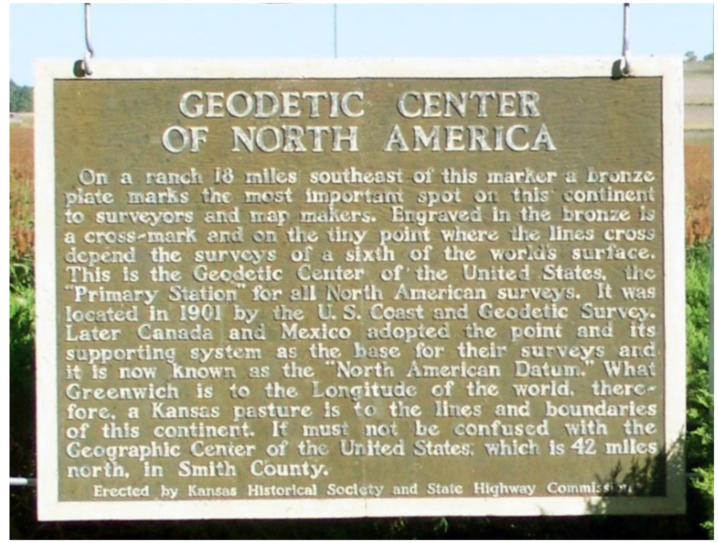
Westchester Co. NY 1933)

United States Coast and Geodetic Survey, Primary Triangulation Between the Maryland and Georgia Base-Lines 1881

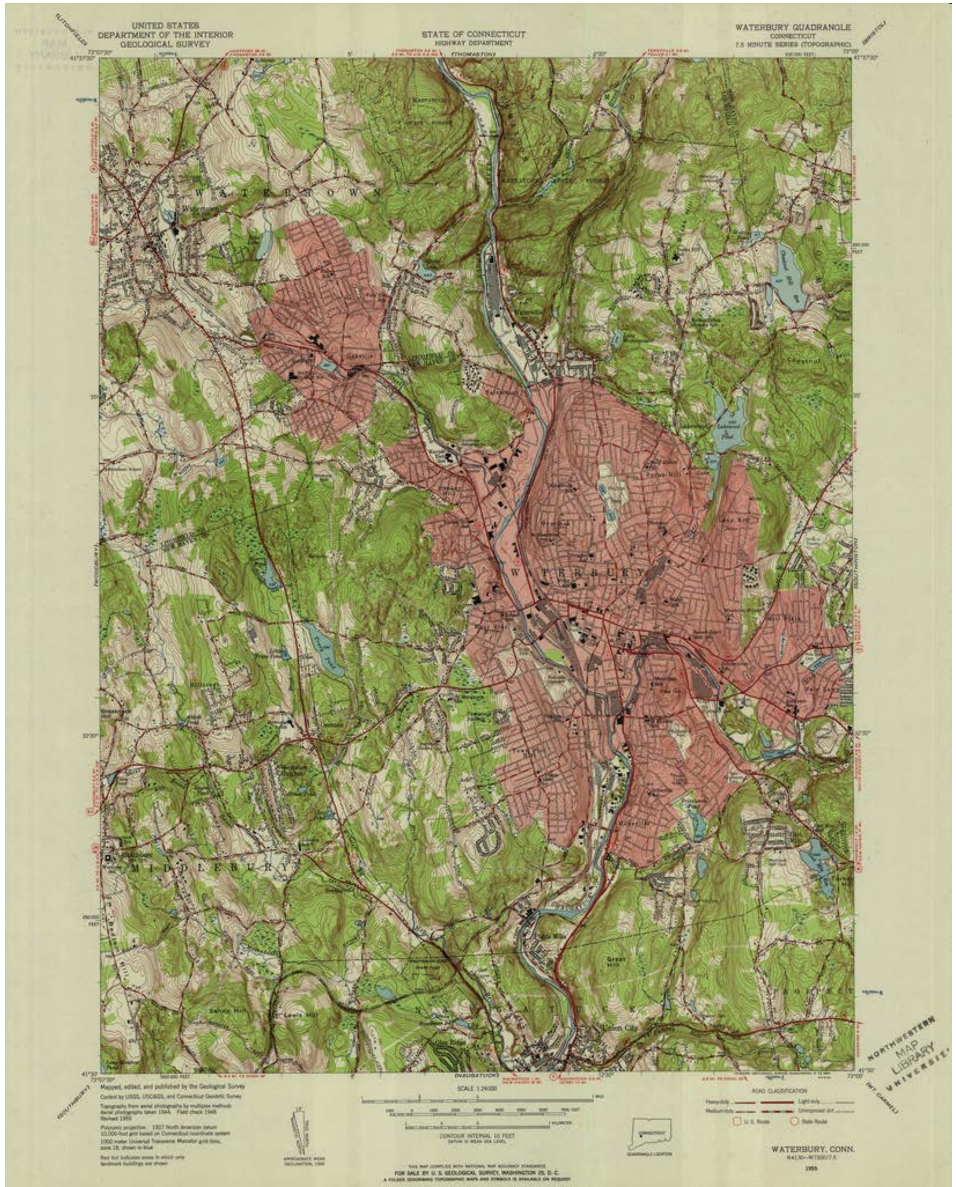


NAD27

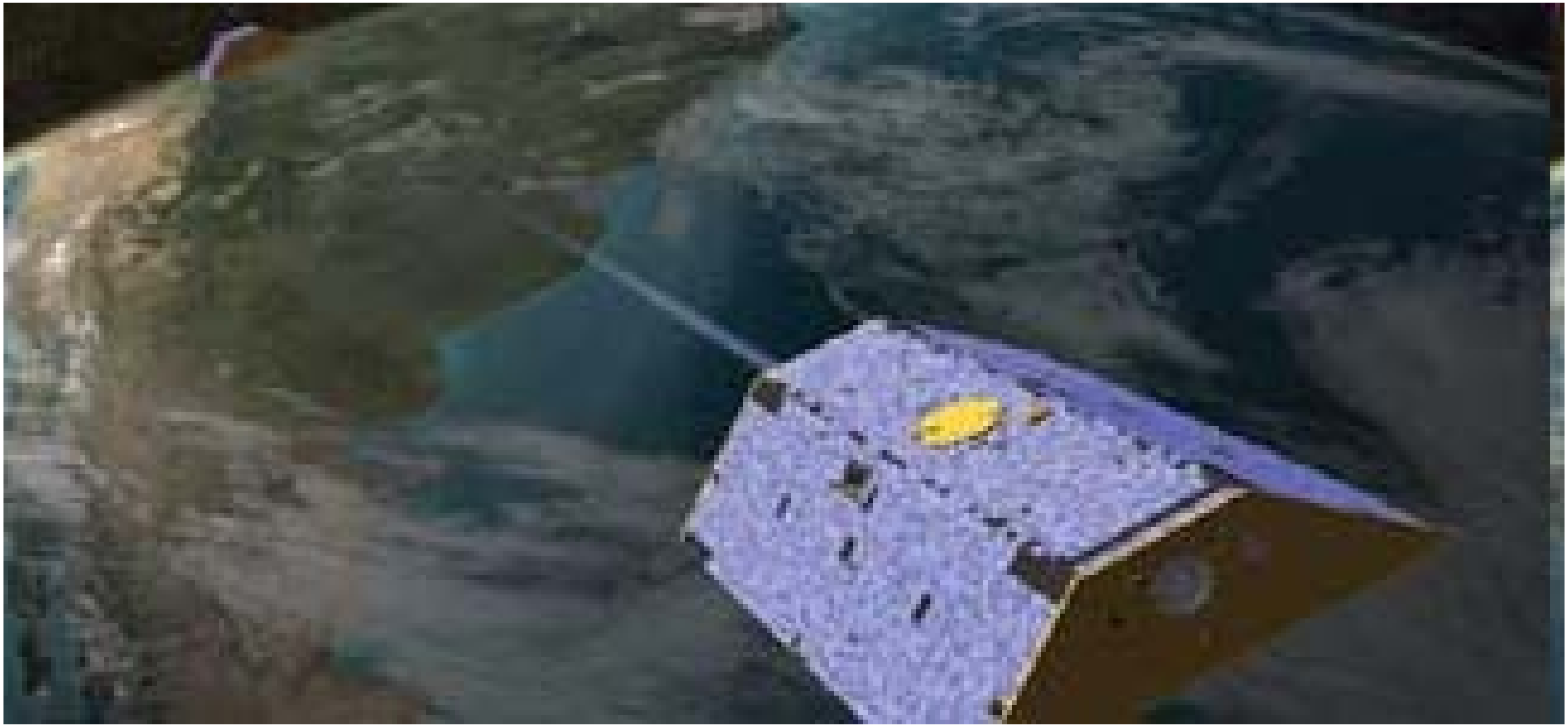
Linking the systems: Meades Ranch



First series US Topo at 1:24,000



The Space Era



WGS72: Doppler shift from satellites

Doppler Satellite Ground Stations Providing Data for WGS 72 Development.

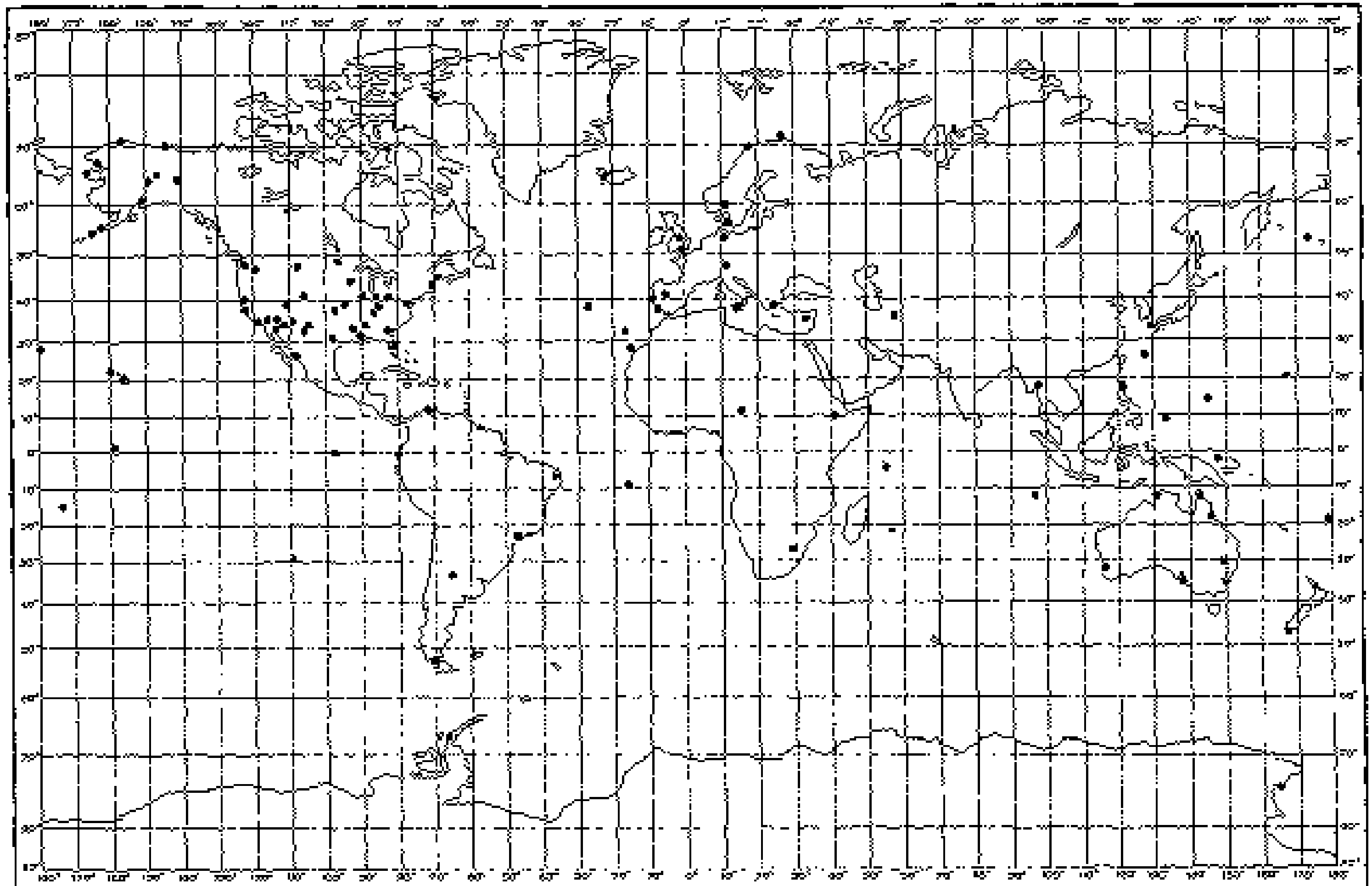


Figure 38

Satellite triangulations

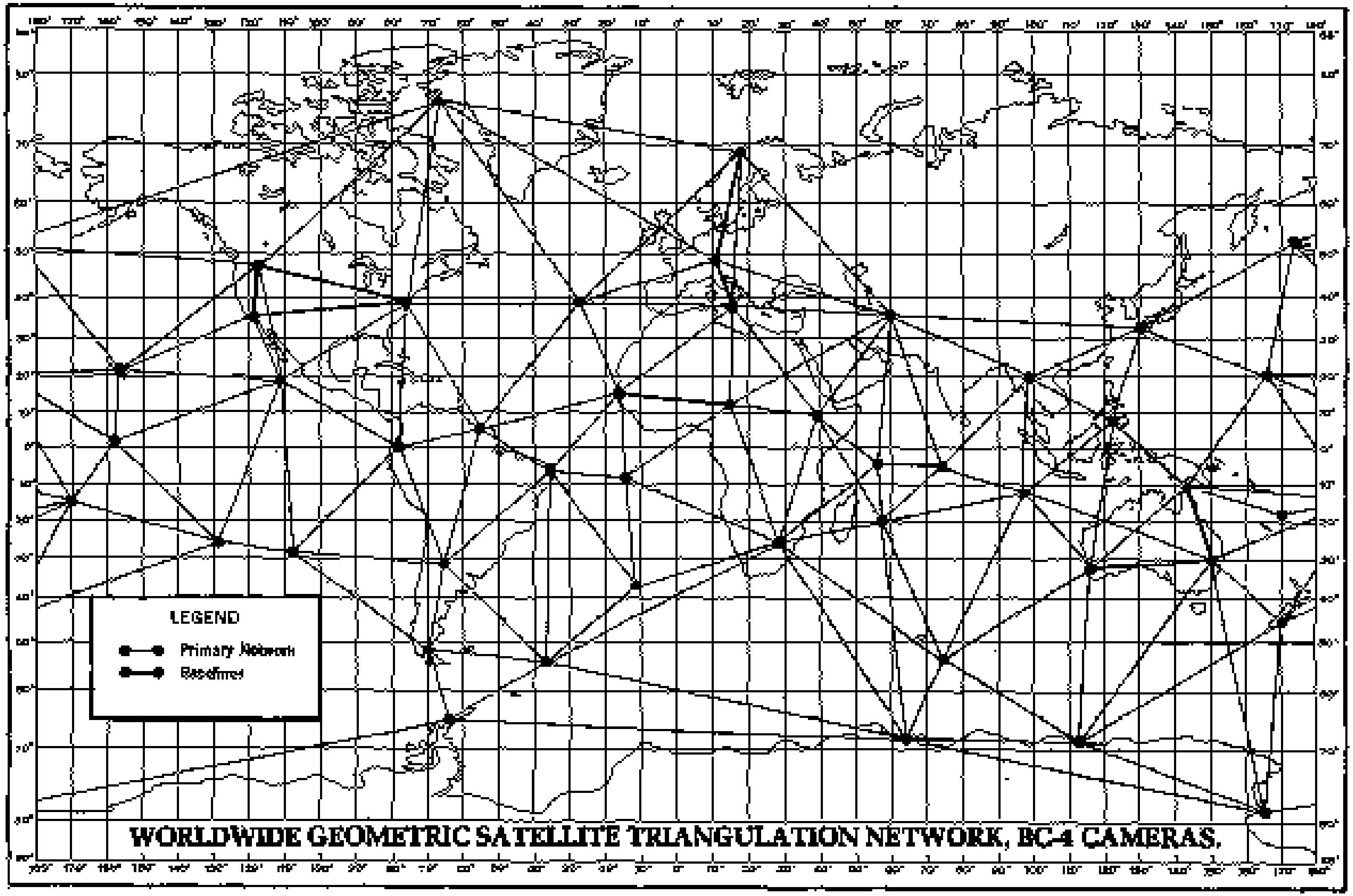
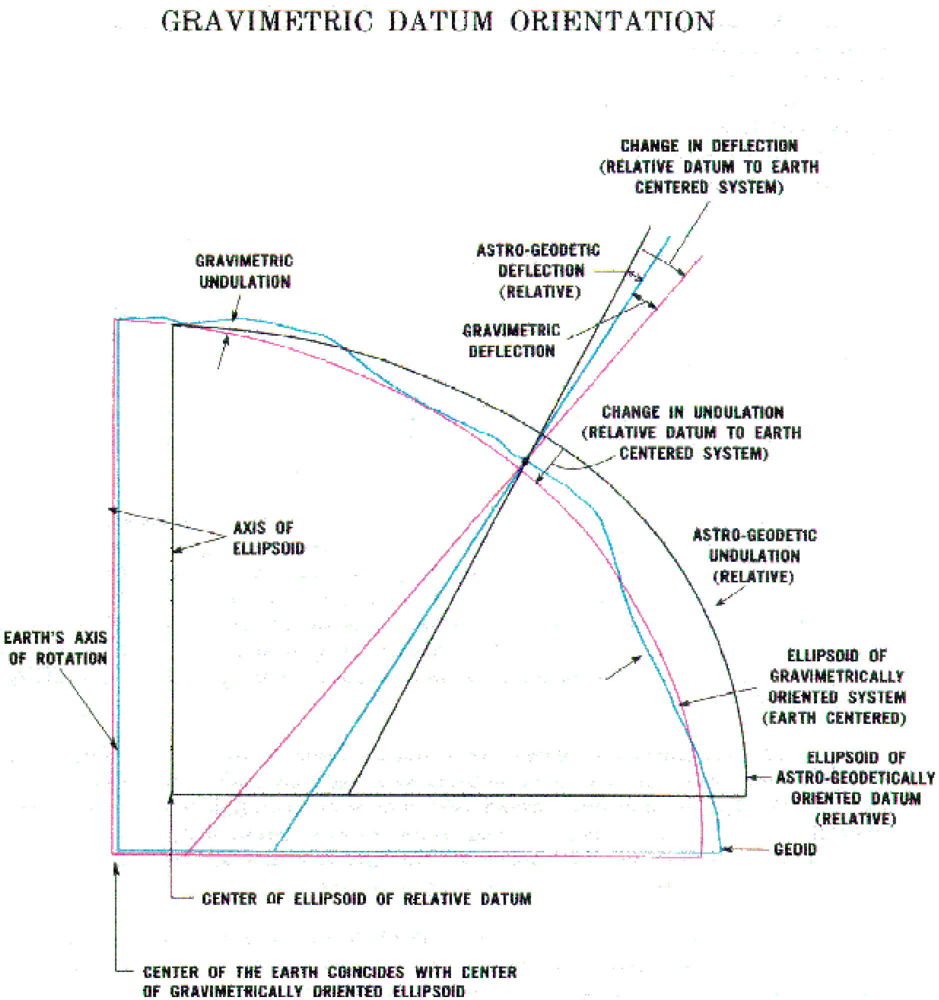


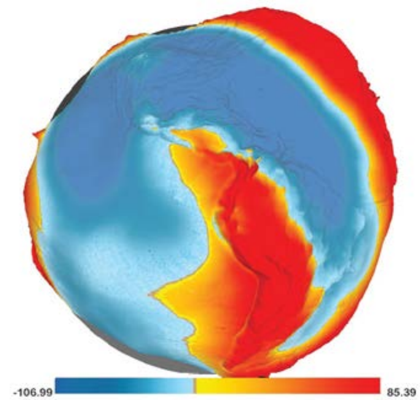
Figure 39

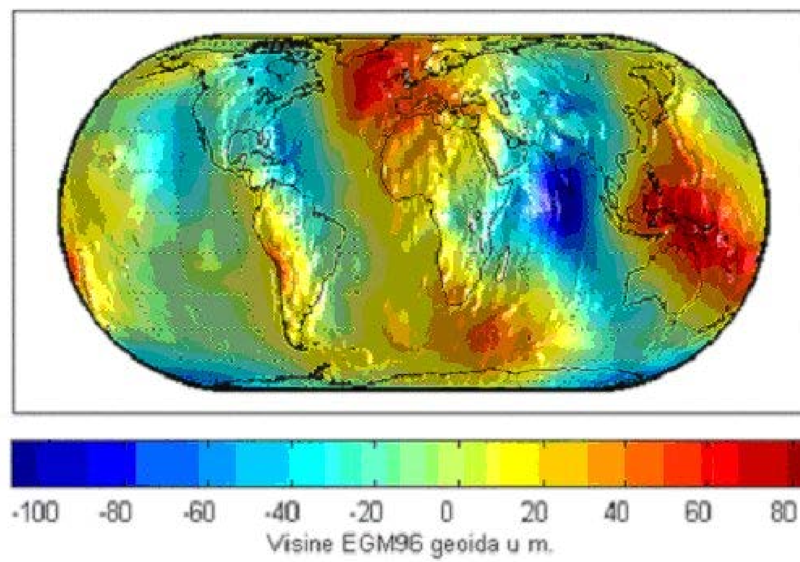
Spy Satellites and geodesy

- The space era created geodetic problems, first noticed by Werner Von Braun in the V2 program
- Needed earth-centered ellipsoid from which to measure geoid differences
- Spy satellites had two missions: search and positioning.
- Maps were poor and included disinformation
- First US program to note issue was CORONA

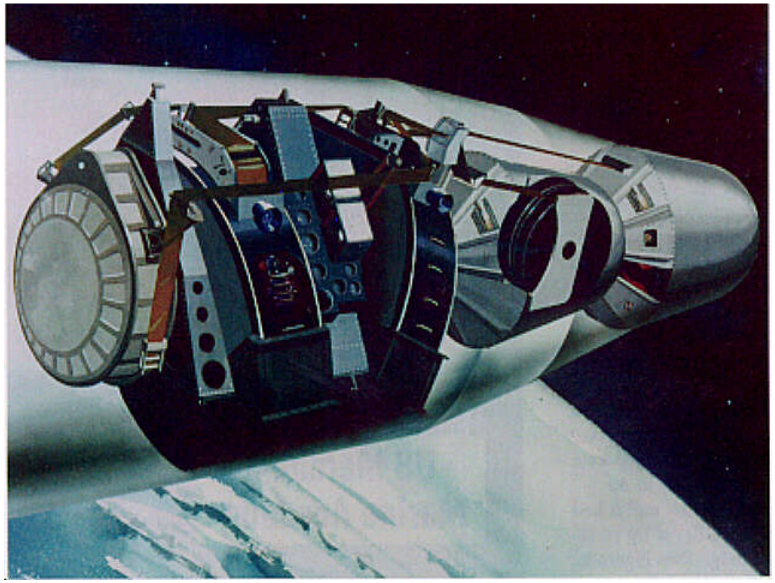
Deflection of the vertical

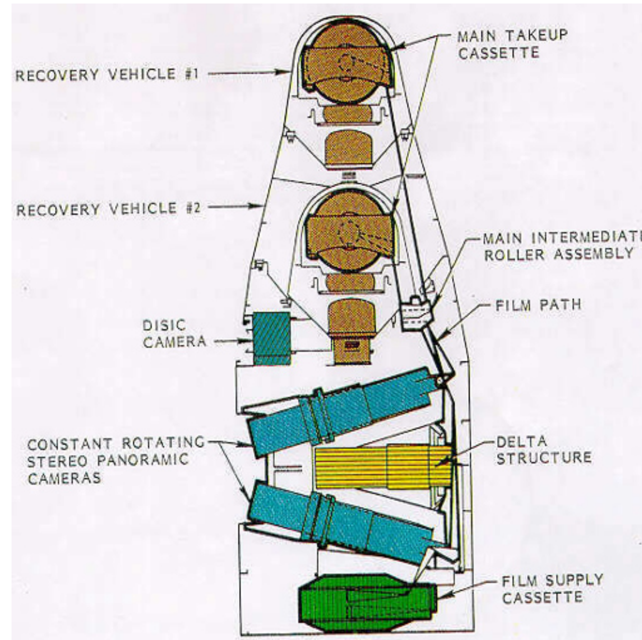


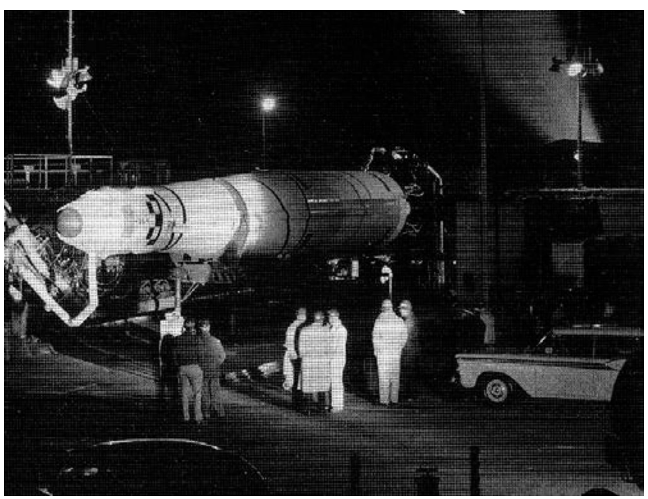


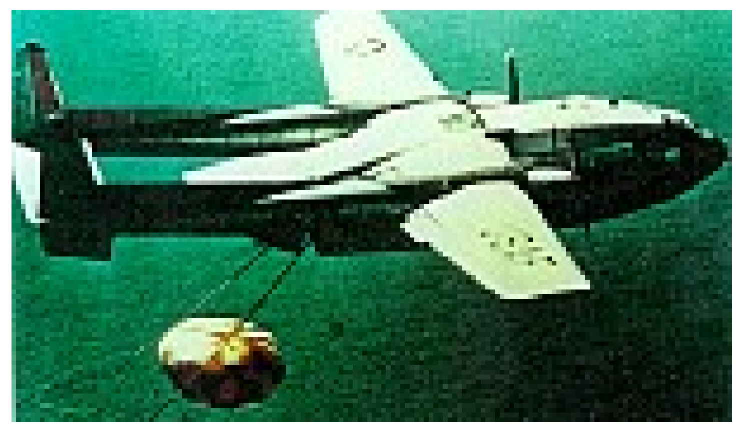


CORONA 1958-72

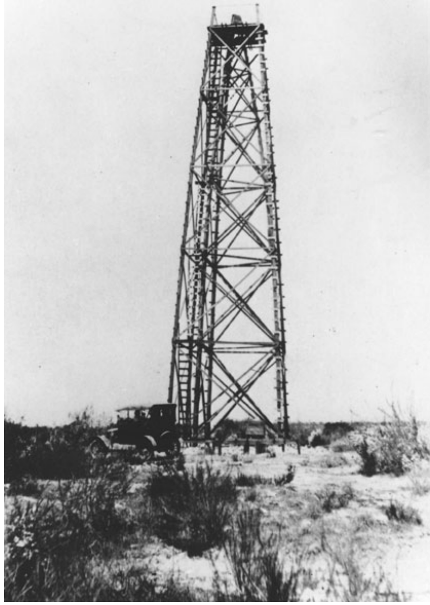






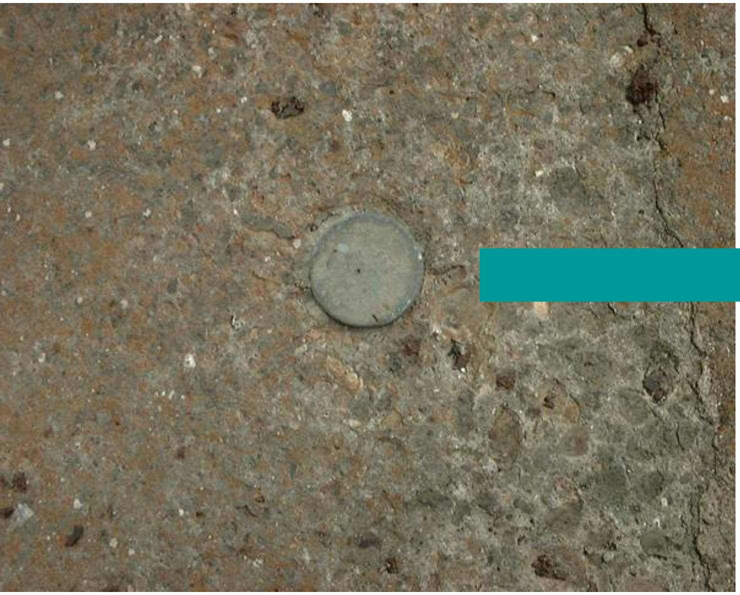


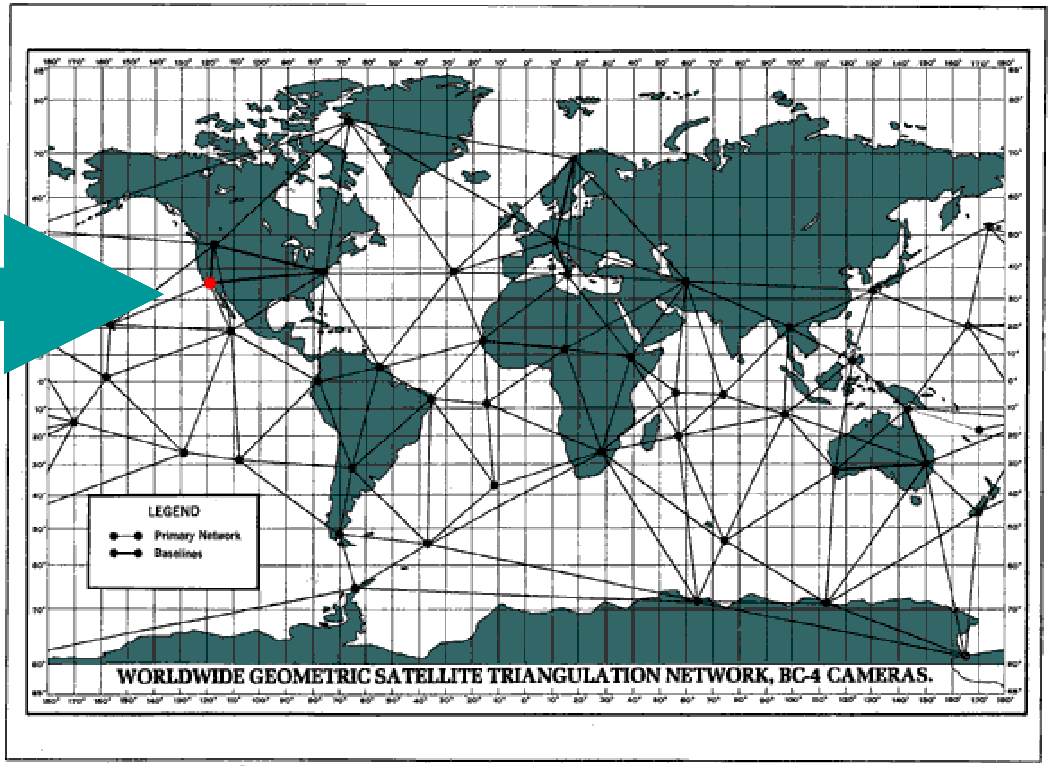
Floyd Hough



- U.S. Army Geodesist dispatched to European theater in October 1944 with 18 men and 3 women
- “a nucleus of German geodesists and mathematicians” sent to US Occupation zone
- 90 tons of captured maps and equipment “German Materials”
- Included German-captured Soviet Czarist era records from the survey for the Trans-Siberian Railway
- Maps showed survey towers that could be found on CORONA imagery

Geodesy and WGS70

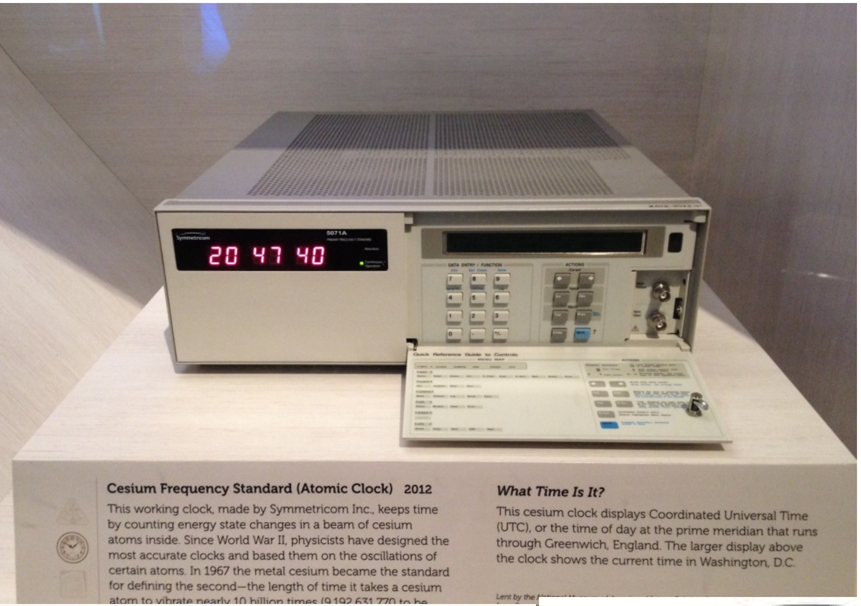




Early GPS


TI 4100 NAVSTAR Navigator
GPS Receiver
Made by Texas Instruments in 1981, this is one of the first commercial GPS receivers and antennas. The National Geodetic Survey, the U.S. Geological Survey, and the Naval Surface Weapons Center at Dahlgren, Virginia, used such receivers for surveying the Earth's precise shape.
Texas Instruments

Later GPS


20 47 40
Cesium Frequency Standard (Atomic Clock) 2012
This working clock, made by Symmetricom Inc., keeps time by counting energy state changes in a beam of cesium atoms inside. Since World War II, physicists have designed the most accurate clocks and based them on the oscillations of certain atoms. In 1967 the metal cesium became the standard for defining the second—the length of time it takes a cesium
What Time Is It?
This cesium clock displays Coordinated Universal Time (UTC), or the time of day at the prime meridian that runs through Greenwich, England. The larger display above the clock shows the current time in Washington, D.C.


A mobile phone in common use in 2012 integrated capabilities found separately in previous navigation tools.
Gift of Becky Bacheller


GLONASS-K
NAVIGATION
SPACECRAFT
CEC


EUROPÄISCHE SATELLITENNAVIGATION

Summary

- Positioning by direct observation became increasingly accurate, eventually revealing the ellipsoid
- Cassinis in France improved mapping by triangulation, reaching a peak in India and the USA
- Colonial powers used meridians to divide the globe
- Issues of a prime meridian resolved by 1884
- Extraordinary measures to define the figure of the earth
- Major changes for the space era-earth centered ellipsoid
- Eventually GPS solves the positioning problem using atomic clocks and trilateration