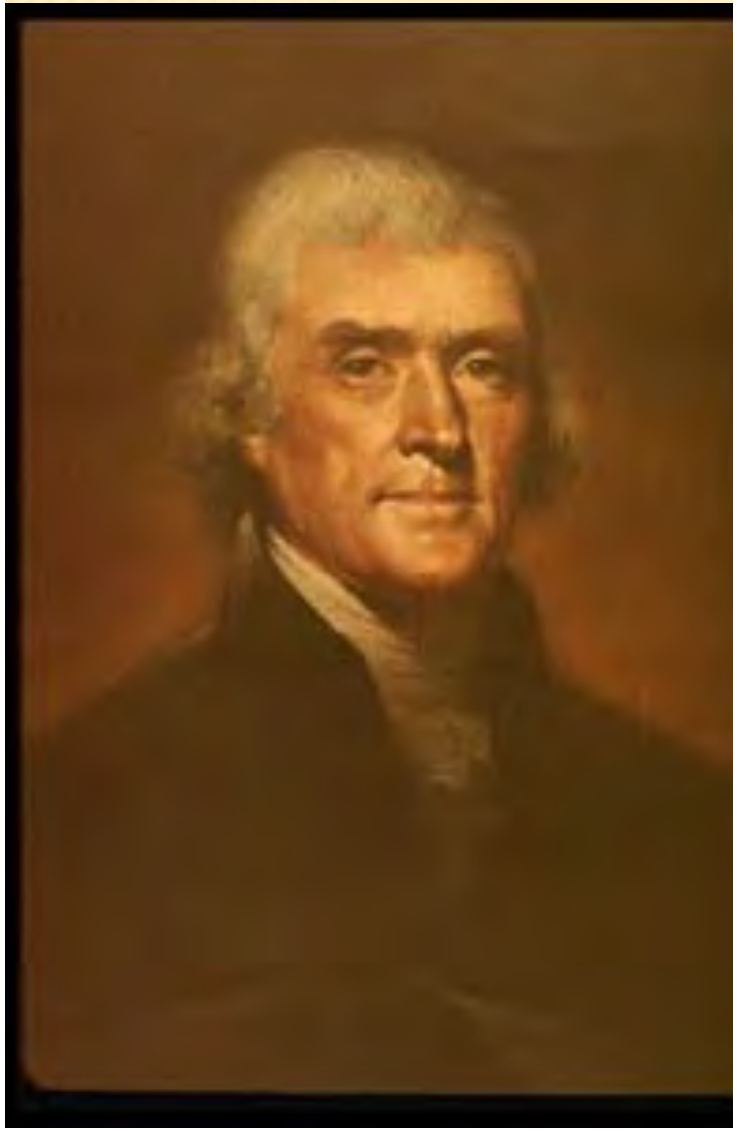
History of the Development of Geodetic Datums in the United States

Vermont Society of Land Surveyors

Colchester

September 5, 2019

Dave Doyle
NGS, Chief Geodetic Surveyor (Retired)
base9geodesy@gmail.com
301-704-9578



NINTH CONGRESS OF THE UNITED STATES.

At the Second Session.

Begun and held at the city of Washington, in the territory of Columbia, on Monday the first of December, one thousand eight hundred and six.

AN ACT *to provide for surveying the coasts of the United States*

Be it enacted by the Senate and House of Representatives of the United States of America, in Congress assembled, that the president of the United States shall be, and he is hereby authorized and requested, to cause a survey to be taken of the coasts of the United States, in which shall be designated the islands and shoals, with the roads or places of anchorage, within twenty leagues of any part of the shore of the United States; and also the respective courses and distances between the principal capes, or head lands, together with such other matters as he may deem proper for completing an accurate chart of every part of the coasts within the extent aforesaid.

Sec. 2. And be it further enacted, that it shall be lawful for the president of the United States, to cause such examinations and observations to be made, with respect to St. George's bank, and any other bank or shoal, and the soundings and currents beyond the distances aforesaid to the gulph stream, as in his opinion may be especially subservient to the commercial interests of the United States.

Sec. 3. And be it further enacted, that the president of the United States shall be, and he is hereby authorized and requested, for any of the purposes aforesaid, to cause proper and intelligent persons to be employed, and also such of the public vessels in actual service, as he may judge expedient, and to give such instructions for regulating their conduct as to him may appear proper, according to the tenor of this act.

Sec. 4. And be it further enacted, that for carrying this act into effect there shall be, and hereby is appropriated, a sum not exceeding fifty thousand dollars, to be paid out of any monies in the treasury, not otherwise appropriated.

Nath. Macon Speaker of the House of Representatives

Geo. Clinton Vice President of the United States, and President of the Senate.

February 10. 1807

Approved

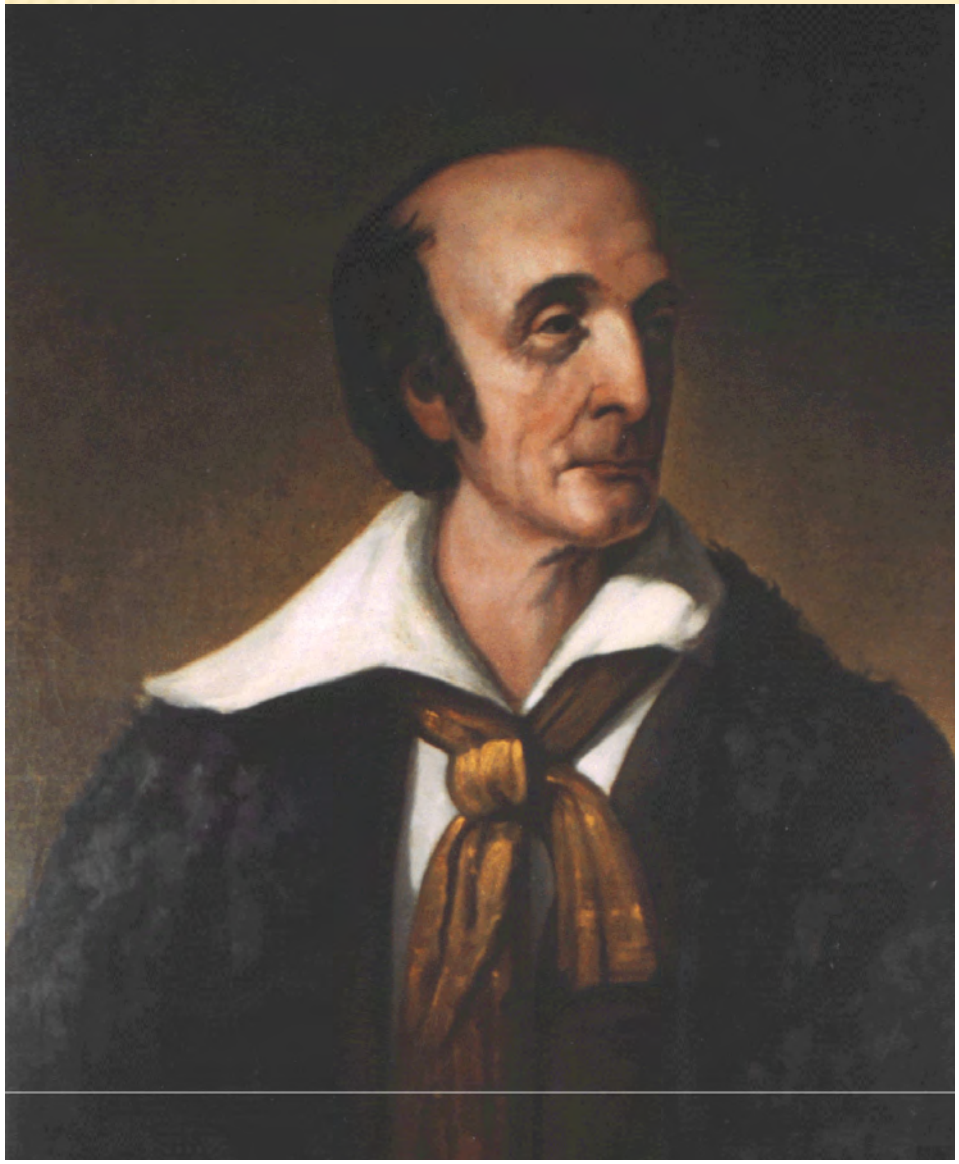
Th: Jefferson

I certify that this act did originate in the House of Representatives.

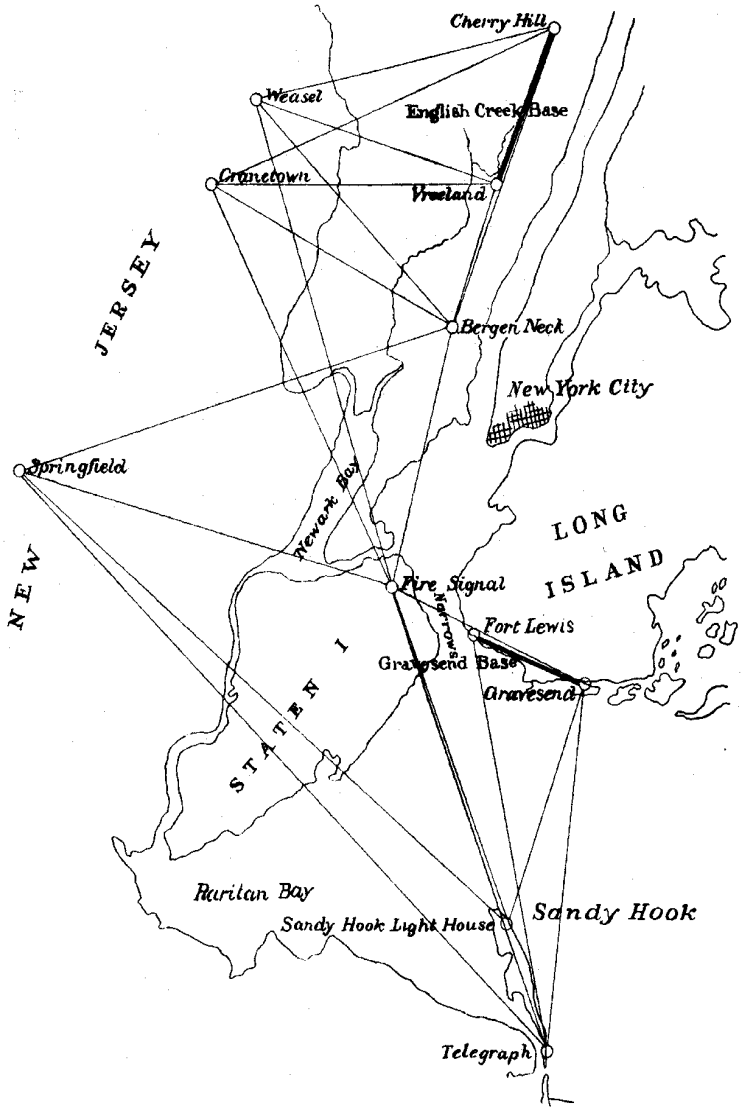
John Beckley Clerk

1807

PRESIDENT THOMAS JEFFERSON SIGNS LEGISLATION ESTABLISHING THE SURVEY OF THE COAST



FERDINAND HASSLER (1770-1843)



Hassler's First Field Work, 1816–1817

24-Inch Troughton & Simms Theodolite in Hassler's Camp
Weight approx. 1000lbs required 10 men to move

Everest's Theodolite Similar to Hassler's

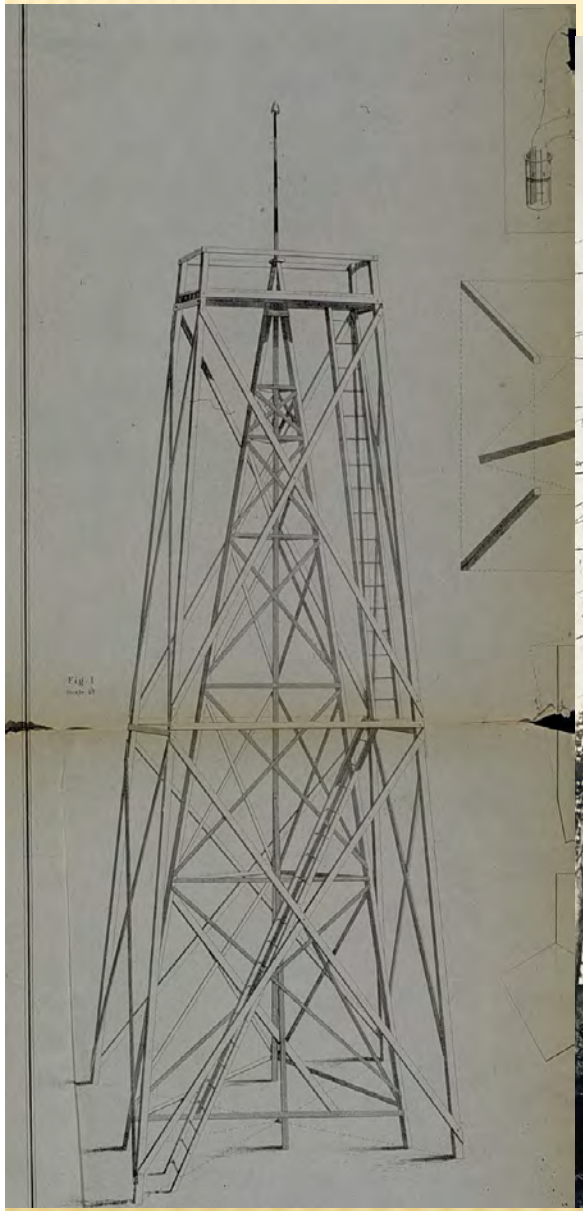
What's In a Name?

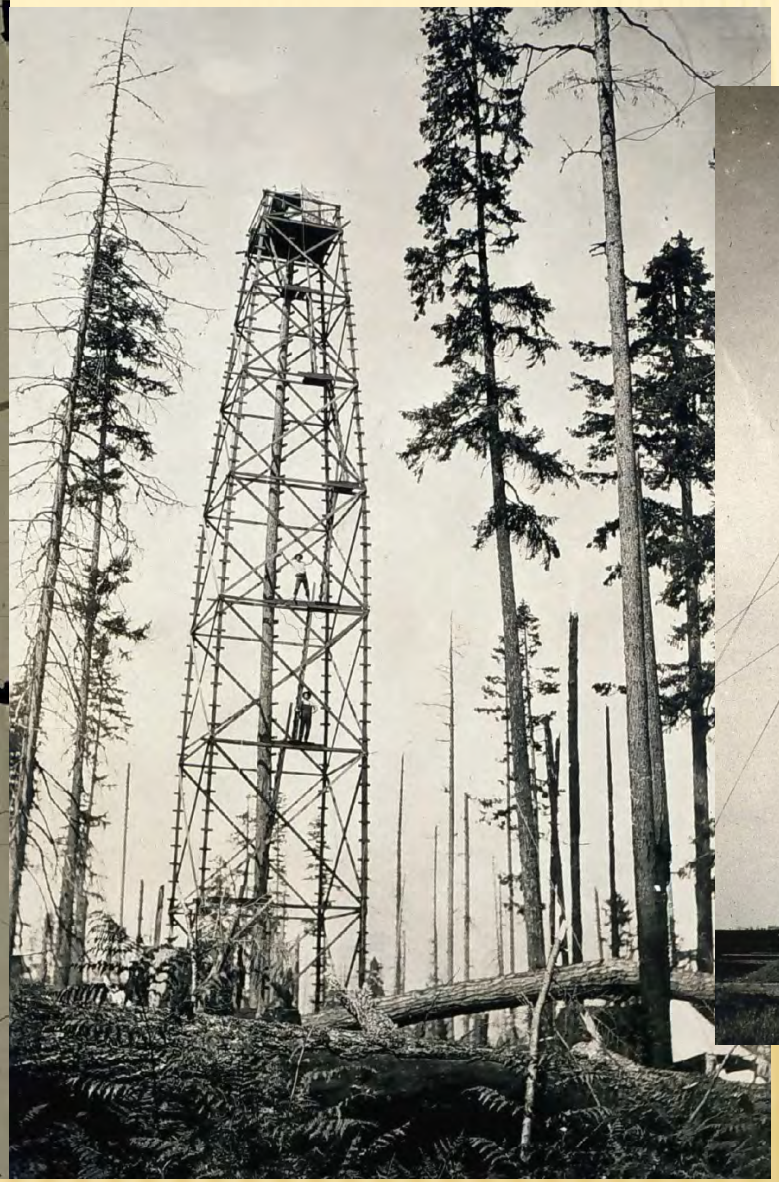
1807 - Survey of the Coast

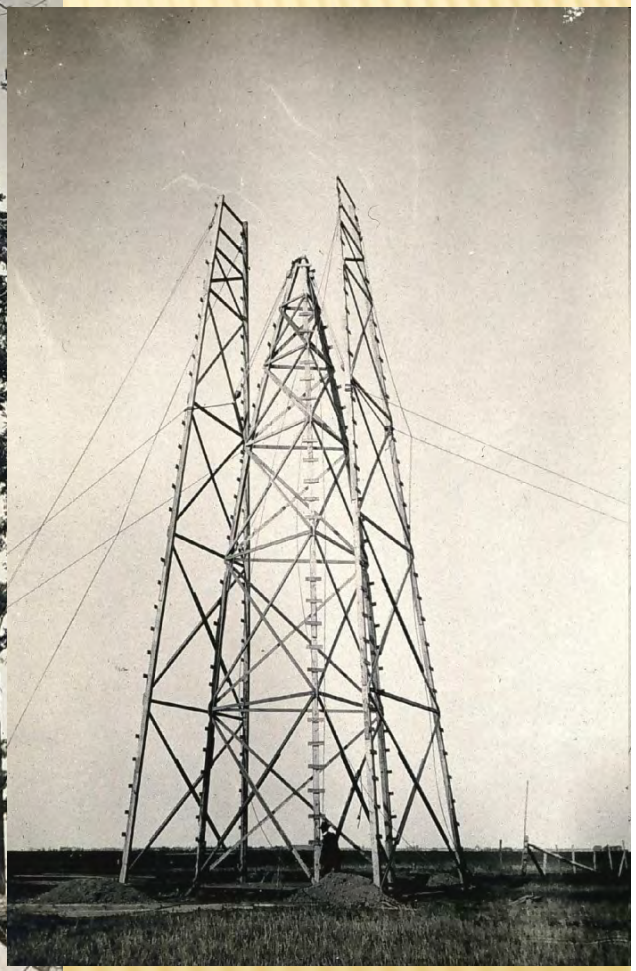
1836 - Coast Survey

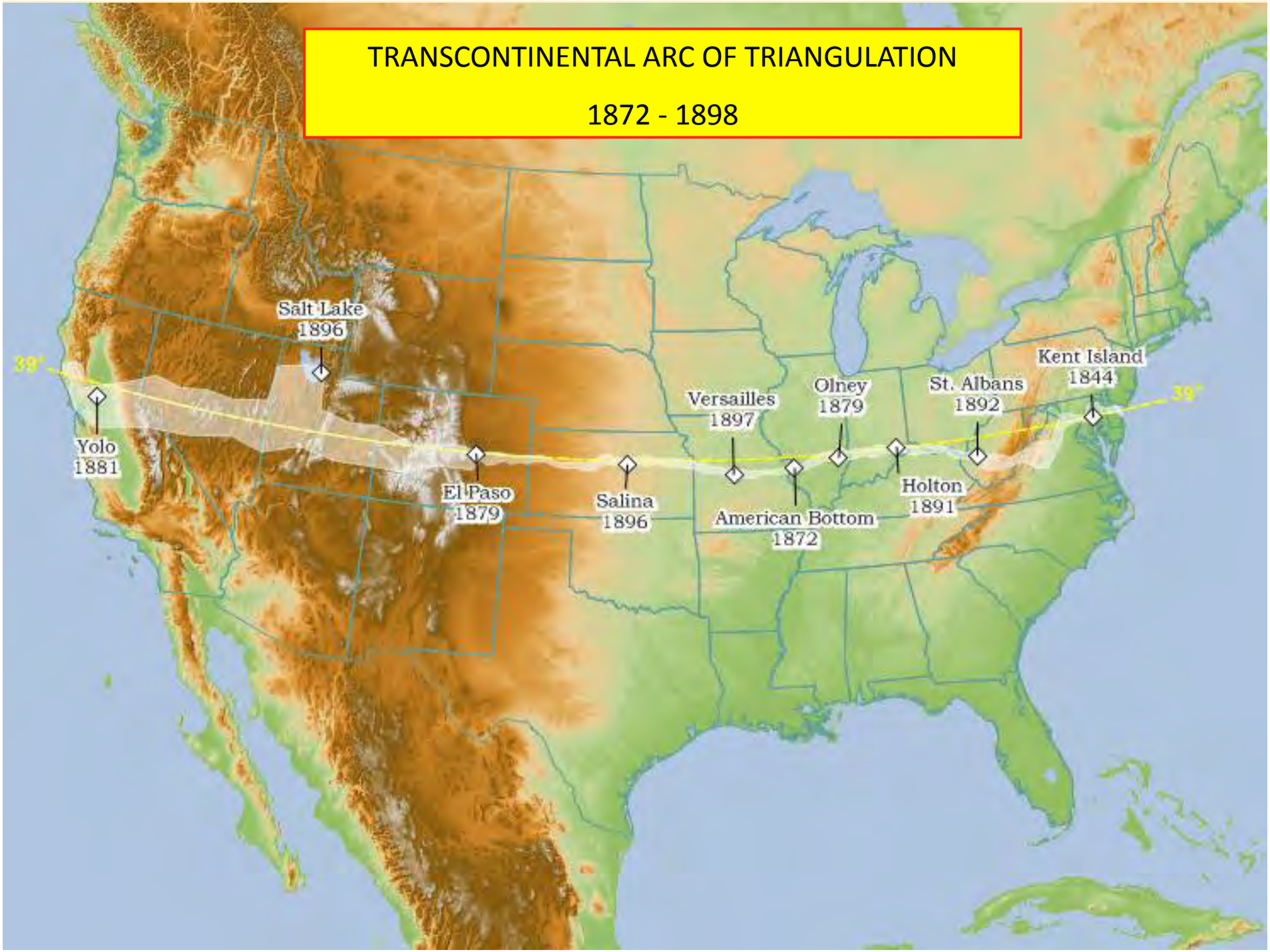
1878 - US Coast and Geodetic Survey

1970 - National Ocean Service
National Geodetic Survey








TRANSCONTINENTAL ARC OF TRIANGULATION
1872 - 1898
Salt Lake
1896
39°
Yolo
1881
El Paso
1879
Salina
1896
Versailles
1897
Olney
1879
St. Albans
1892
Kent Island
1844
39°
Holton
1891
American Bottom
1872

August 28 to September 22, 1885

HIGH SUMMIT STATION, TUSHAR MOUNTAIN, UTAH, SHOWING RING WALL AND DOUBLE SHELTER TENT AGAINST STORMS AND RADIATION OF HEAT.

Altitude, 3,702 meters or 12,146 feet.

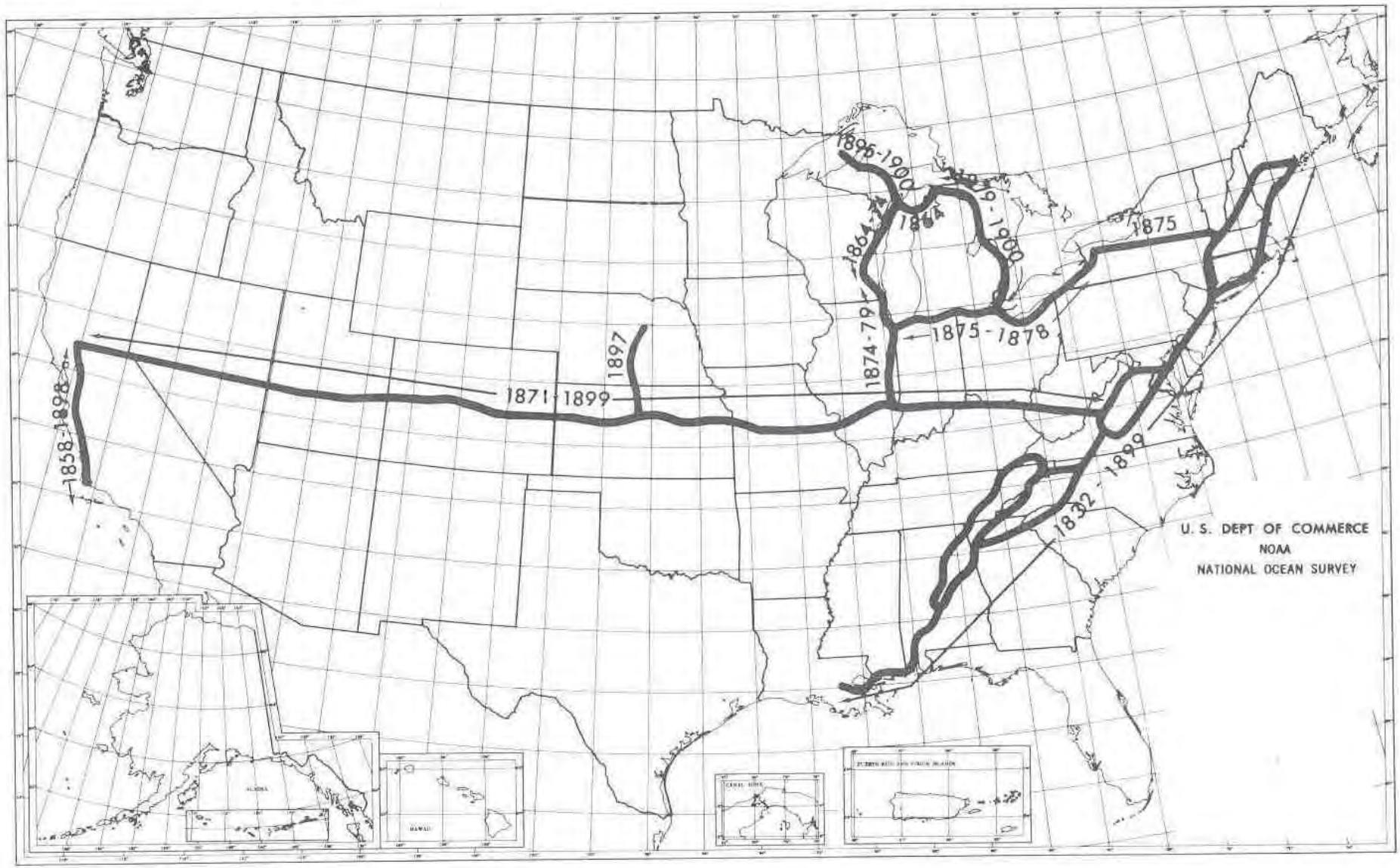
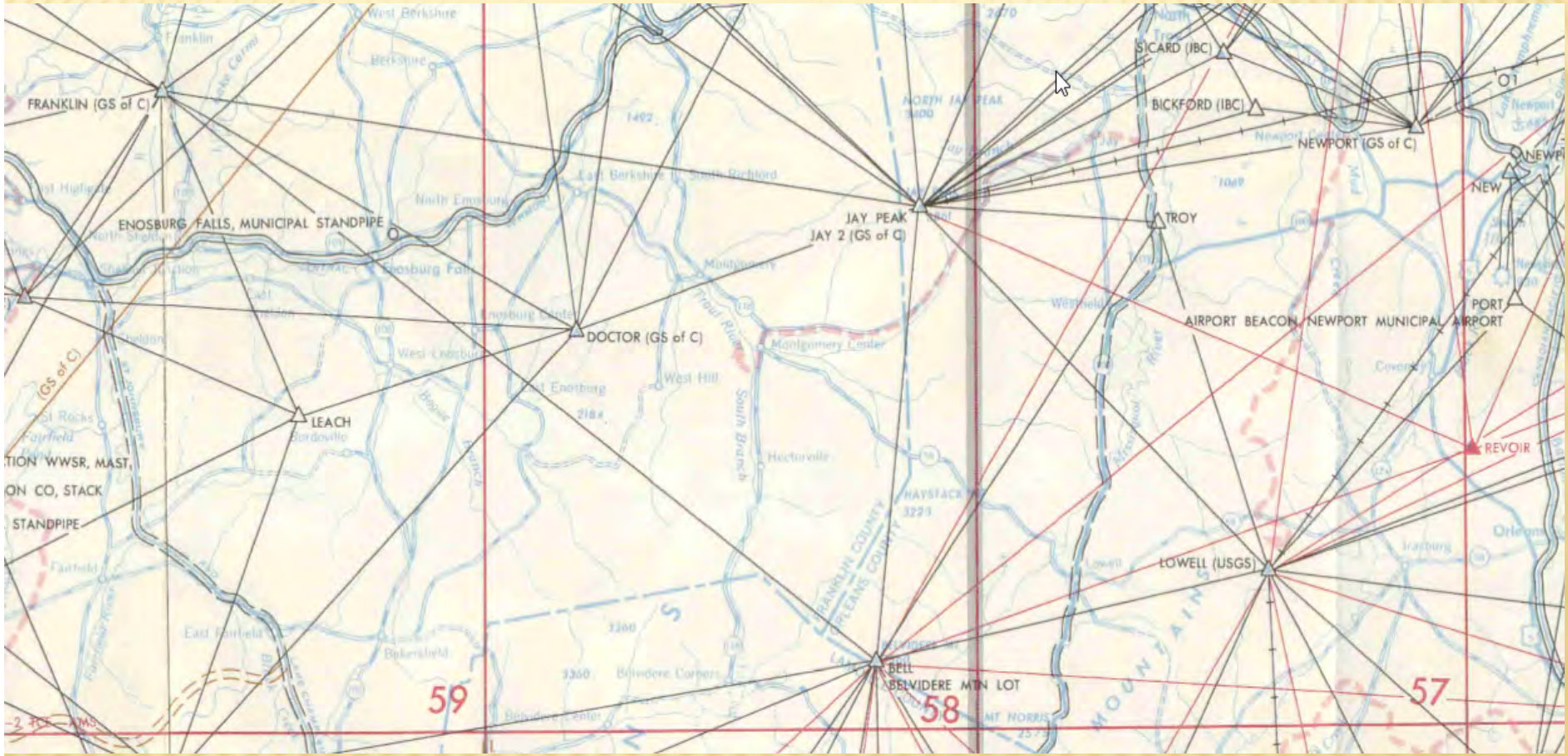


Figure 1

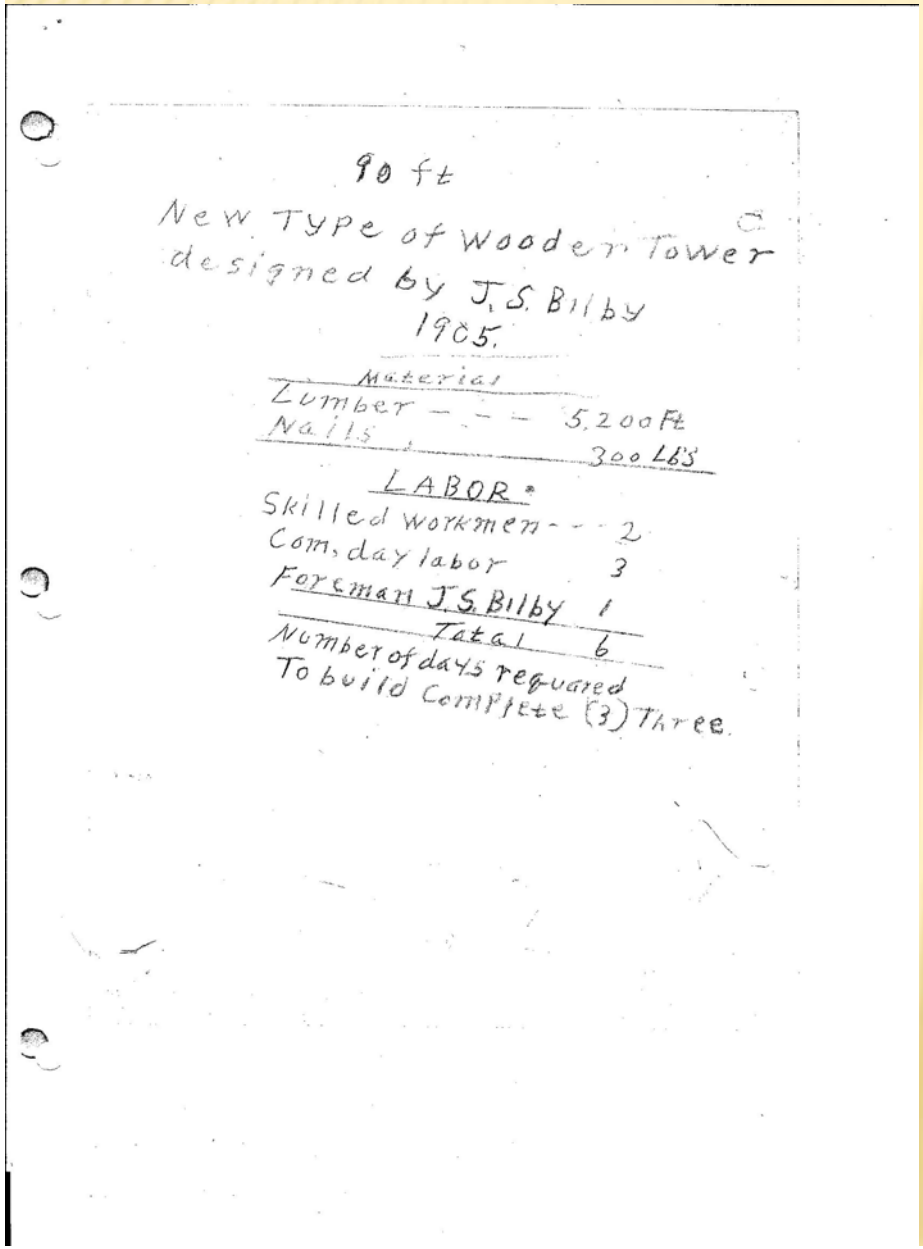
Geodetic Control For 1901 Adjustment - The North American Datum

Triangulation Schemes



JASPER BILBY

Tower Construction



90 ft

New Type of Wooden Tower
designed by J. S. Bilby
1905.

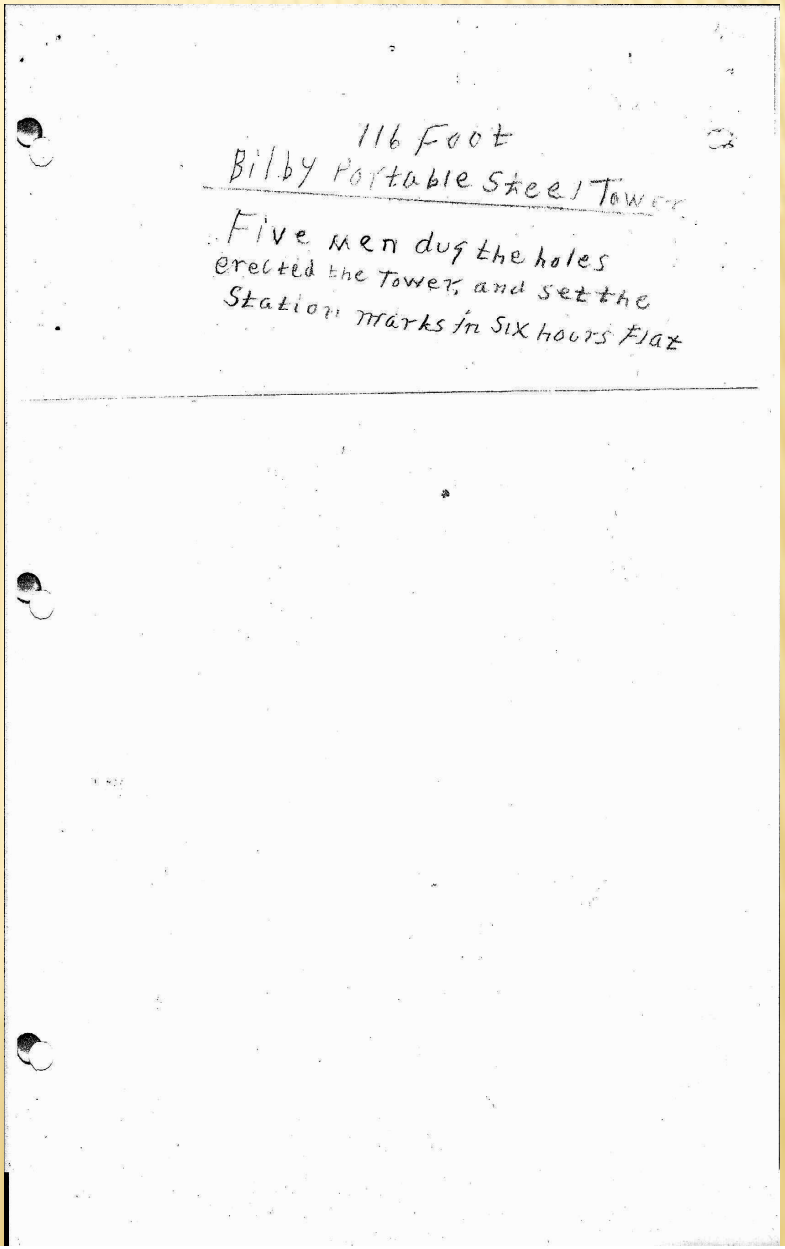
Material

Lumber - - -	5,200 Ft
Nails	300 Lbs

LABOR.

Skilled workmen - -	2
Com. day labor	3
Foreman J. S. Bilby	1
Total	6

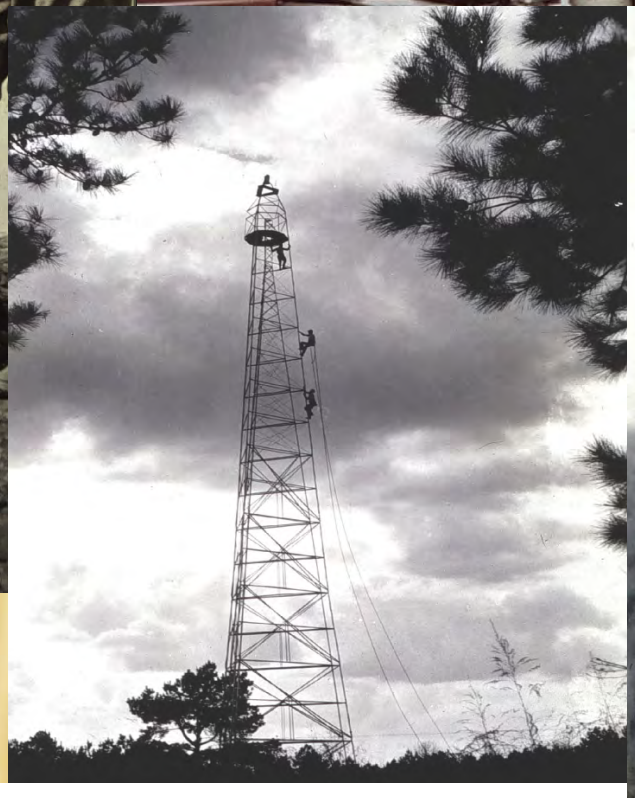
Number of days required
To build Complete (3) Three.



116 Foot
Bilby Portable Steel Tower

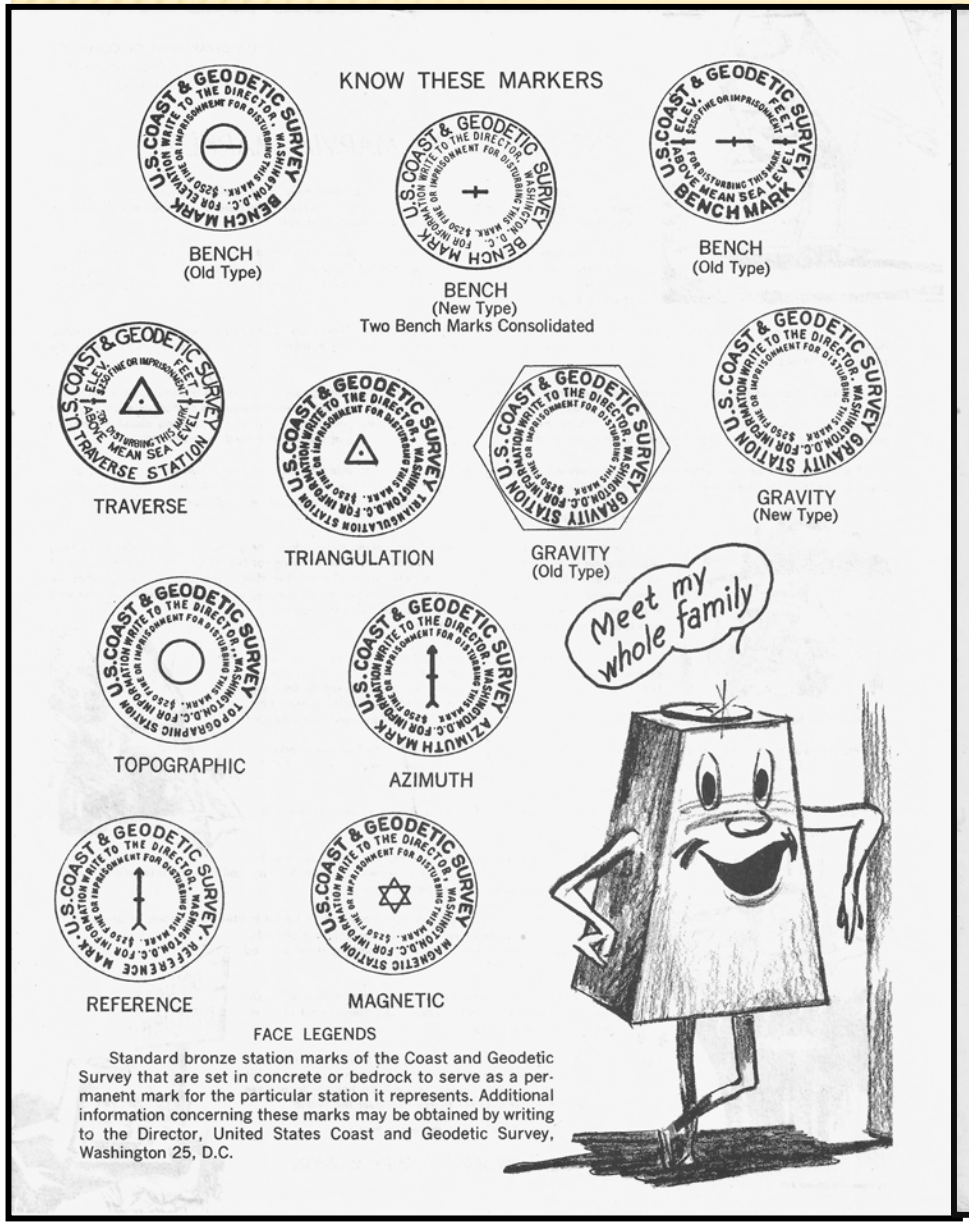
Five men dug the holes
erected the Tower, and set the
Station marks in Six hours Flat

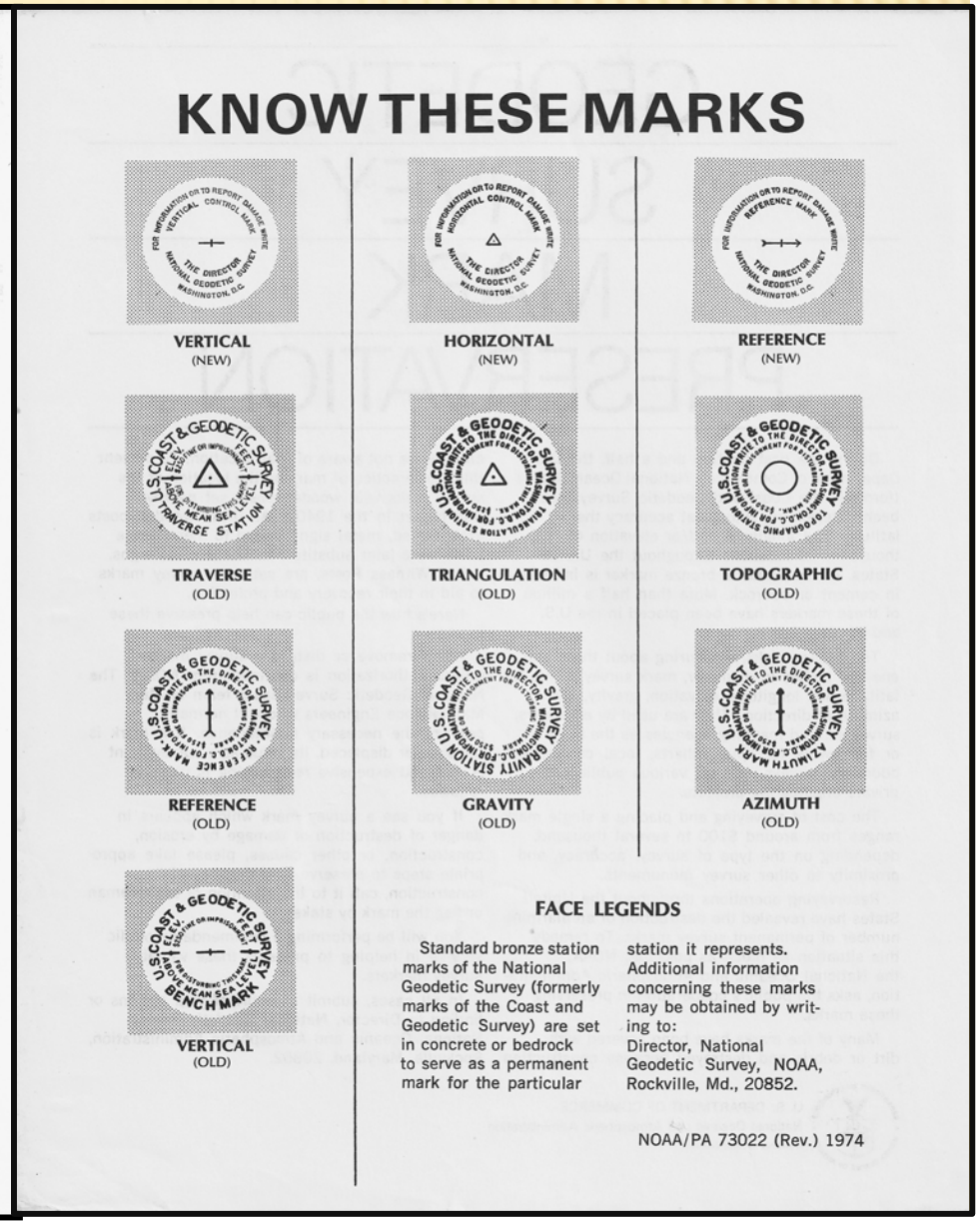
BILBY TOWER CONSTRUCTION



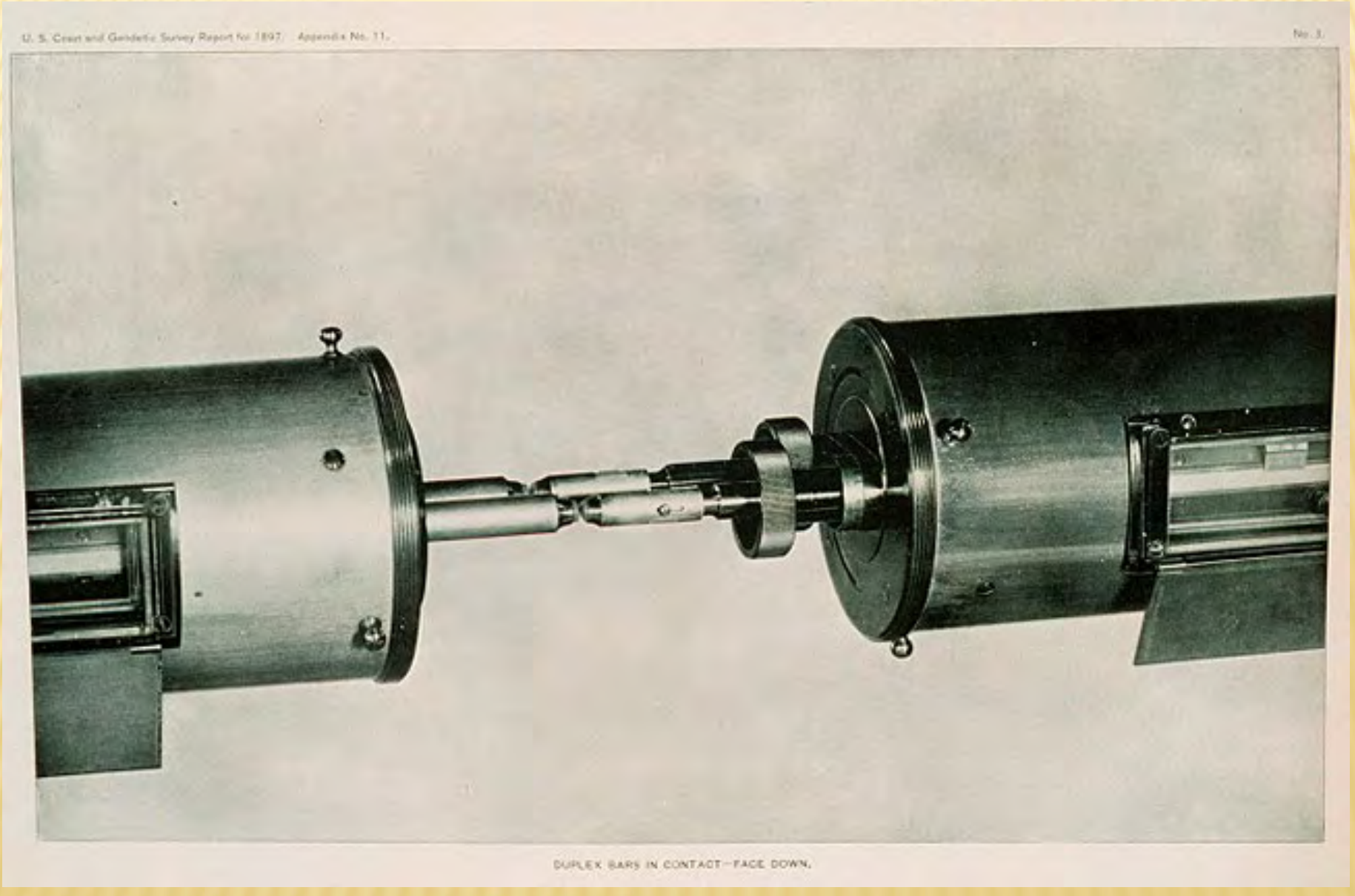
USC&GS GEODETIC NOMADS

USC&GS/NGS Marker Types





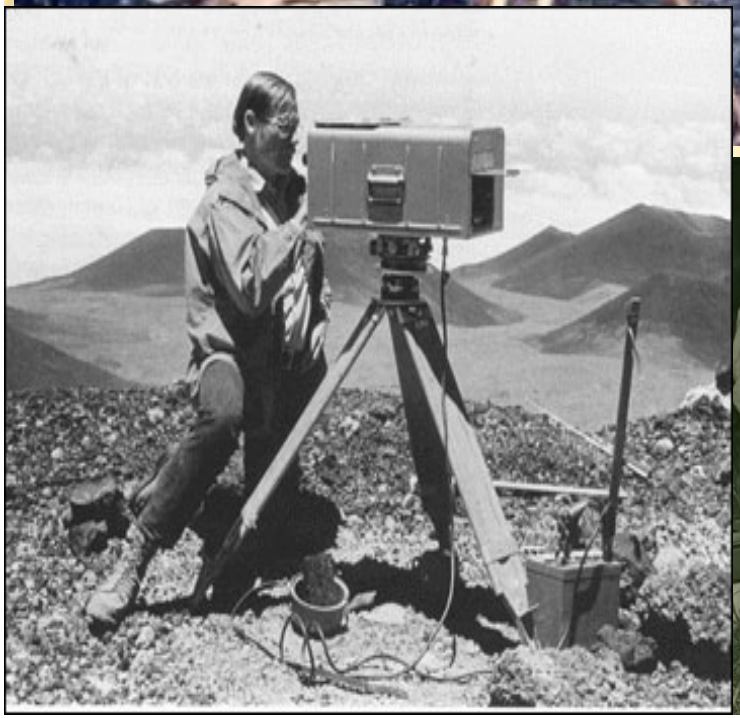
Cutting Edge Surveying Technology circa 1890



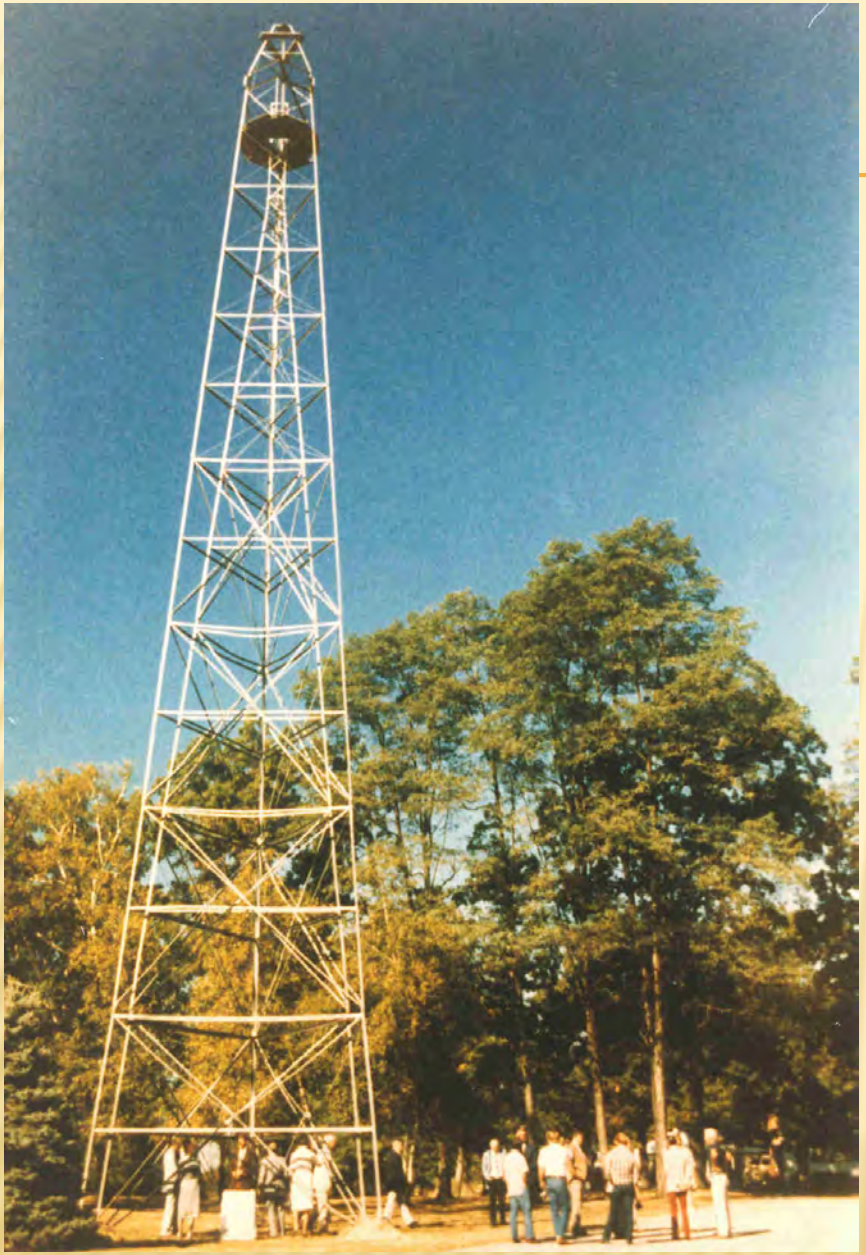
Salina, KS Baseline Measurement – 1896
6.5 km/4.1 mi required about 5 weeks
Precision ~ 8 mm/0.03 ft (1:721,600)

Advances in distance measurement technology
Early 1900s

Electronic technology 1950s - 1970



A Game Changer



1984
AN END OF AN ERA

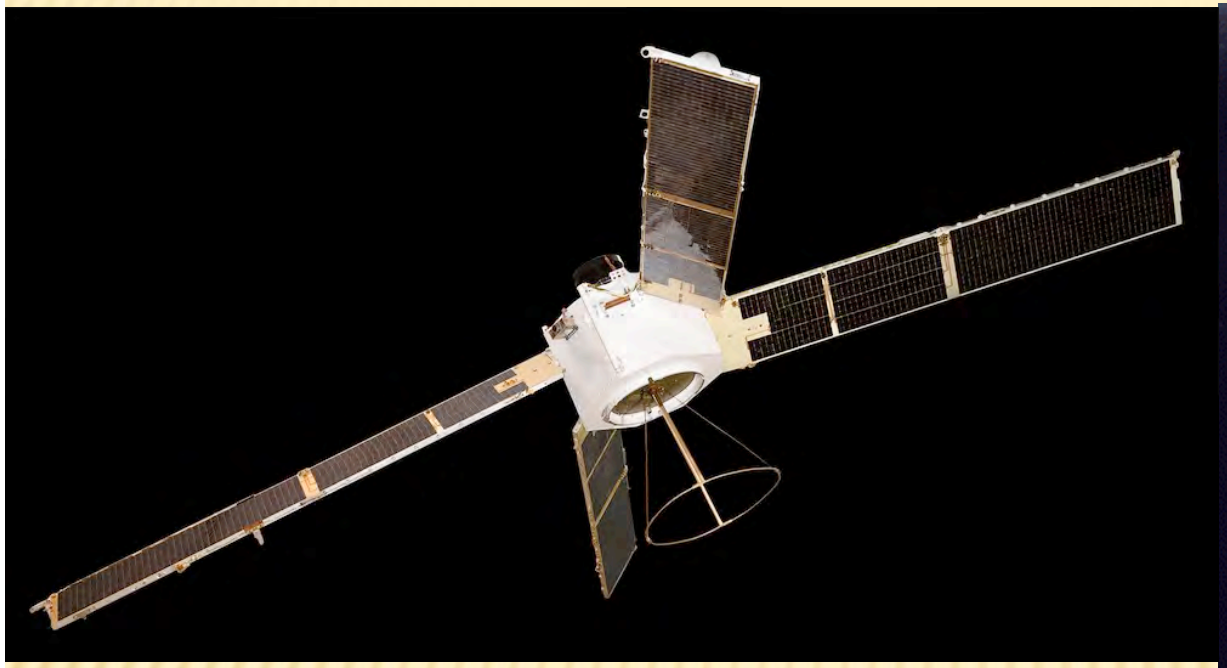
GLOBAL SATELLITE TRIANGULATION NETWORK

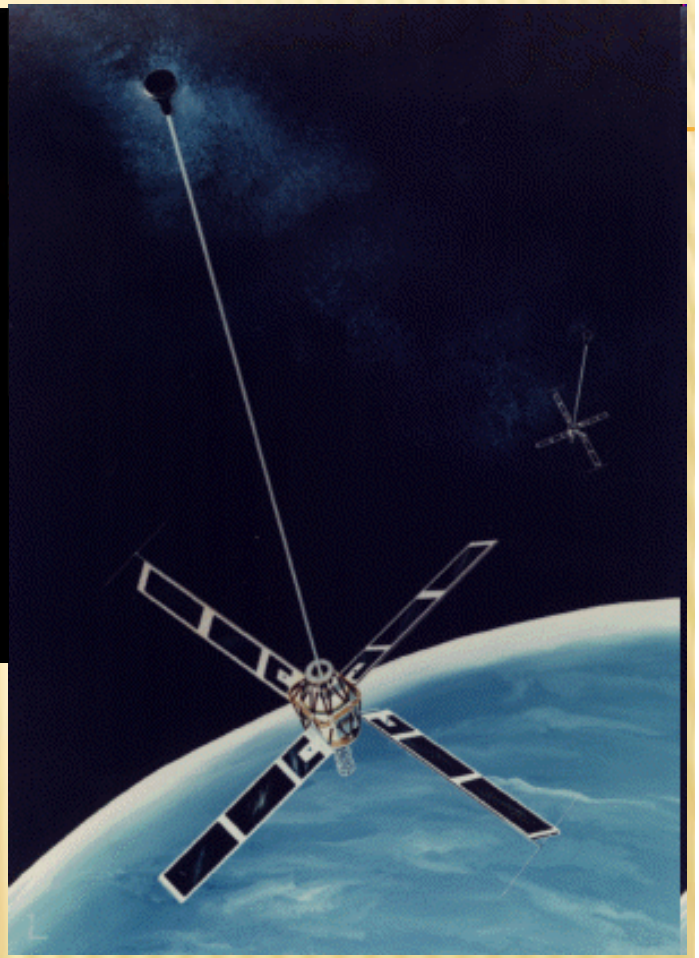
(BC-4)

1964-1973

ECHO/PAGEOS BALLOON SATELLITE TYPE PHOTOGRAPHED BY BC-4

BC-4 CAMERA PHOTOGRAPH
PAGEOS SATELLITE AGAINST THE STAR BACKGROUND





U.S. NAVY NAVSAT TRANSIT SATELLITE "Doppler"

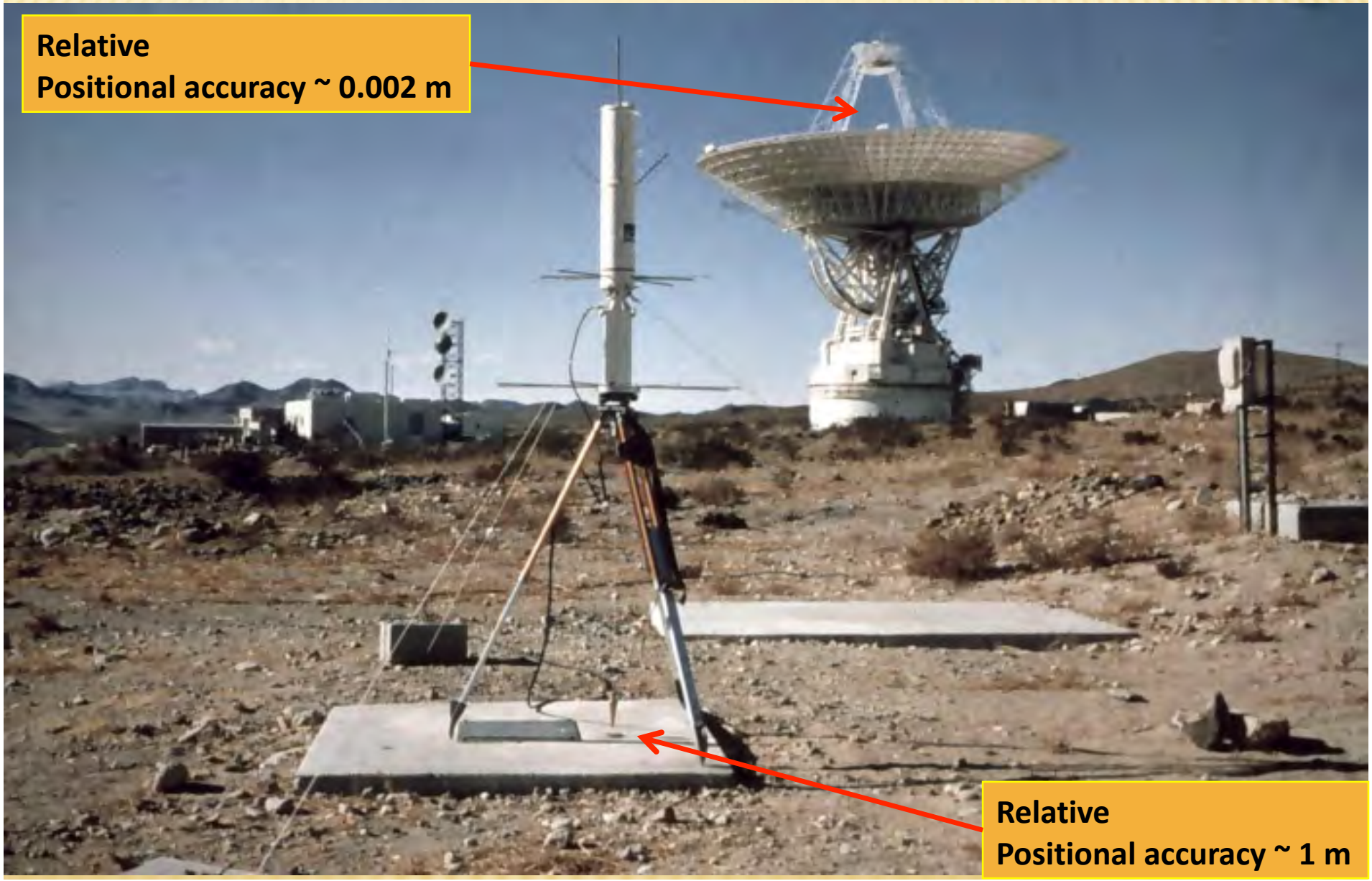
Prototype Launched (Failed) 1959

First Successful Test 1960

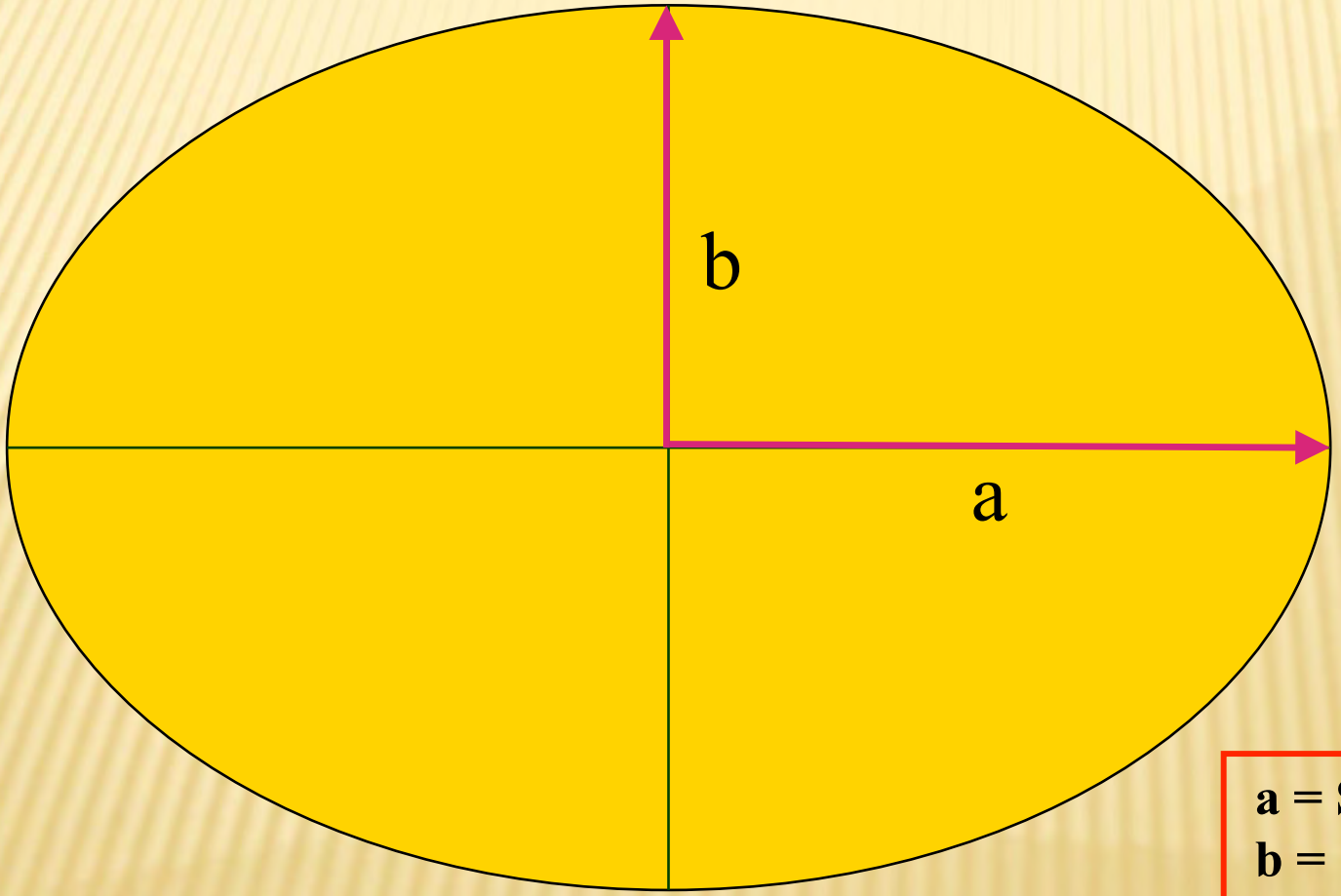
Operational 1964 (Military)

Civilian Access 1967

Transit Geoceiver and VLBI

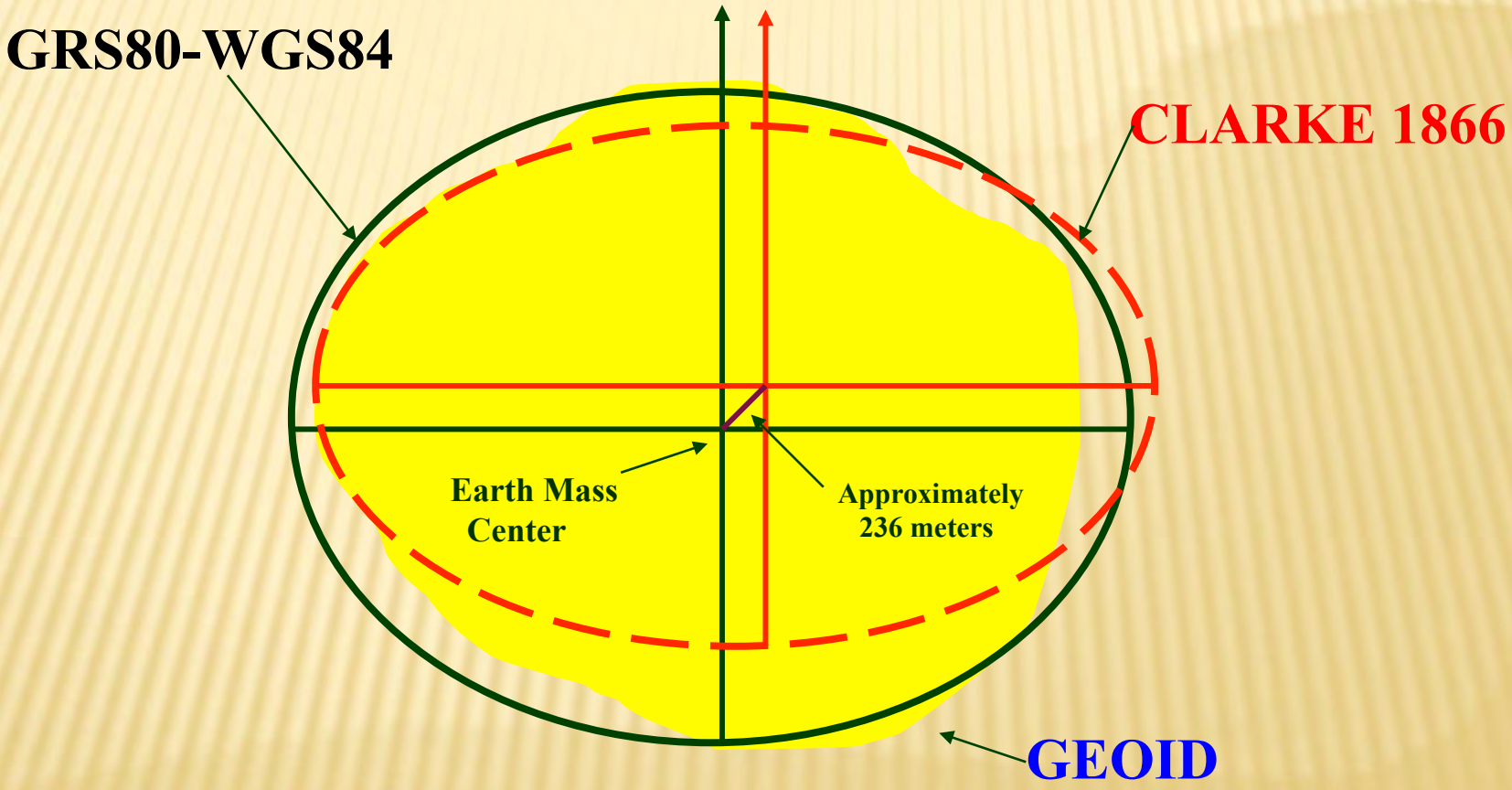


The Ellipsoid
Mathematical Model of the Earth



a = Semi major axis
b = Semi minor axis
f = $\frac{a-b}{a}$ = Flattening

The Geoid and Two Ellipsoids



Ellipsoids Used in the United States

BESSEL 1841
a = 6,377,397.155 m 1/f = 299.1528128
(1848 – 1880)

CLARKE 1866
a = 6,378,206.4 m 1/f = 294.97869821
(1880 – 1986)

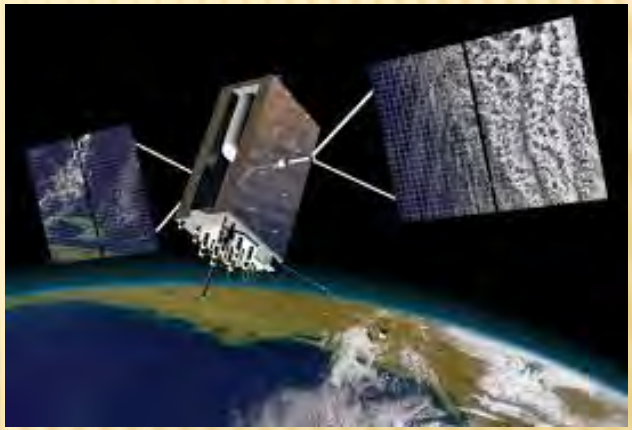
GEODETIC REFERENCE SYSTEM 1980 - (GRS 80)
a = 6,378,137 m 1/f = 298.257222101
(1986 – Present)
(International Union of Geodesy and Geophysics Standard)

WORLD GEODETIC SYSTEM 1984 - (WGS 84)
a = 6,378,137 m 1/f = 298.257223563
Defined by U.S. Defense Mapping Agency (DMA) for GPS

Global Positioning System

GPS Block I

GPS Block II



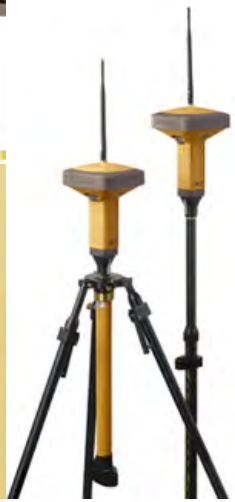
GPS Block III

- February 22, 1978 - 1st NAVSTAR Satellite launched
- July 17, 1995 - System Fully Operational
- May 1, 2000 - Selective Availability turned off
- September 26, 2005 - L2C band added
- May 28, 2010 - First L5 Satellite added
- December 23, 2018 – First Block III scheduled for launch
- 2020? - 10-50 cm real-time accuracy! Maybe Sooner!

NO GROUND CONTROL!

Macrometer V-1000 GPS Receiver
1982 ~ appox. $250,000 each

Where are we now??



National Spatial Reference System (NSRS)

Consistent National Coordinate System

- **Latitude/Northing**
- **Longitude/Easting**
- **Height**
- **Scale**
- **Gravity**
- **Orientation**

and how these values change with time

Designed and maintained by NOAA's National Geodetic Survey

NSRS Control Components

- **Networks of passive geodetic control points**
  - Classical passive survey monuments
  - Approx. 1 million individual horizontal and/or vertical stations published by NGS.

- **National CORS Network**
  - A network of Continuously Operating Reference Stations
  ~ 2000+ Active Stations from 239 partner organizations.

NSRS Control Components

NSRS Control Components

EARLY NAD 83 NETWORK PROBLEMS

Not "GPSABLE"

Poor Station Accessibility

Irregularly Spaced

Positional Accuracy

HIGH PRECISION GPS NETWORK (HPGN)
HIGH ACCURACY REFERENCE NETWORK (HARN)
1989 - 1997

"GPSABLE"
Clear Horizons for Satellite Signal Acquisition

EASY ACCESSIBILITY
Few Special Vehicle or Property Entrance Requirements

REGULARLY SPACED
Always within 20-100 Km

HIGH ACCURACY
A-Order (5 mm + 1:10,000,000) (3 5.5 hr sessions)
B-Order (8mm + 1:1,000,000) (2 5.5 hr sessions)

AVERAGE NAD 83 (1986) POSITIONAL CHANGE
0.40 m / 1.3 ft

FEDERAL & COOPERATIVE BASE NETWORKS (FBN/CBN) 1997 -2004

More State Partnerships

Reduce distortions in early HARNS (3-10 cm)

Ensure Connections to CORS

Improve ellipsoid height accuracy (Not worse than 2 cm)

No adjustment of old triangulation or GPS if FBN/CBN results were less than 5 cm

NAD 83 (2007)

NAD 83 (2011)

During 2009-2010 NGS completes multi-year solution of 2000+ CORS

Data from January 1994 to April 2011

Replaced relative GPS antenna calibrations with absolute calibrations

More consistent national set of coordinates Maine to Guam

National adjustment of 81,000+ passive stations to fit new CORS coordinates

Average shift from NAD 83 (2007) to NAD 83 (2011)

HISTORY OF VERTICAL DATUM IN THE U.S.

National Geodetic Vertical Datum 1929 (NGVD 29)

Original name: "General Adjustment of 1929"
Changed to Sea Level Datum of 1929 in 1940s
Changed to NGVD 29 in 1973

"Zero height" held fixed at 26 tide gauges
Not all on the same tidal datum epoch (~ 19 yrs)

Did not account for Local Mean Sea Level variations from the geoid

Thus, not truly a "geoid based" datum


NGVD29
The National Geodetic Vertical Datum of 1929 is referenced to 26 tide gauges in the US and Canada
Prince Rupert
Fort Stephens
San Francisco
San Diego
Galveston
Biloxi
Pensacola
Fernandina Beach
Brunswick
St. Augustine
Cedar Keys
Norfolk
Old Point Comfort
Annapolis
Baltimore
Atlantic City
Perth Amboy
Boston
Portland
Yarmouth
Halifax
Father's Point
© 2008 Europa Technologies
© 2008 Tele Atlas
Image NASA
Image © 2008 TerraMetrics
©2008 Google

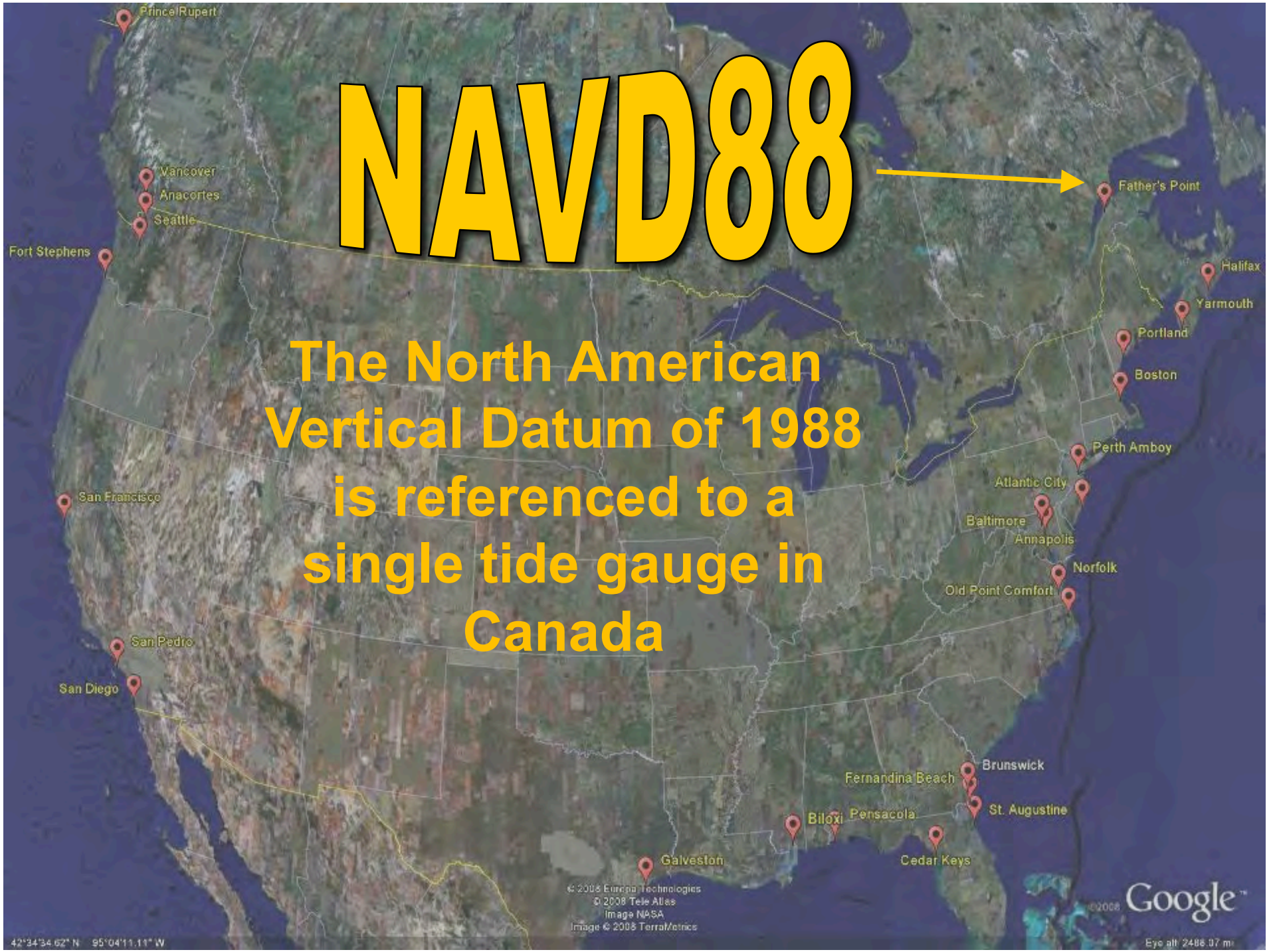
HISTORY OF VERTICAL DATUM IN THE U.S.

NORTH AMERICAN VERTICAL DATUM OF 1988

Use of one fixed height removed local sea level variation problem of NGVD 29

Use of one fixed height did open the possibility of unconstrained cross-continent error build up

The H=0 surface of NAVD 88 was supposed to be parallel to the geoid…(close again)

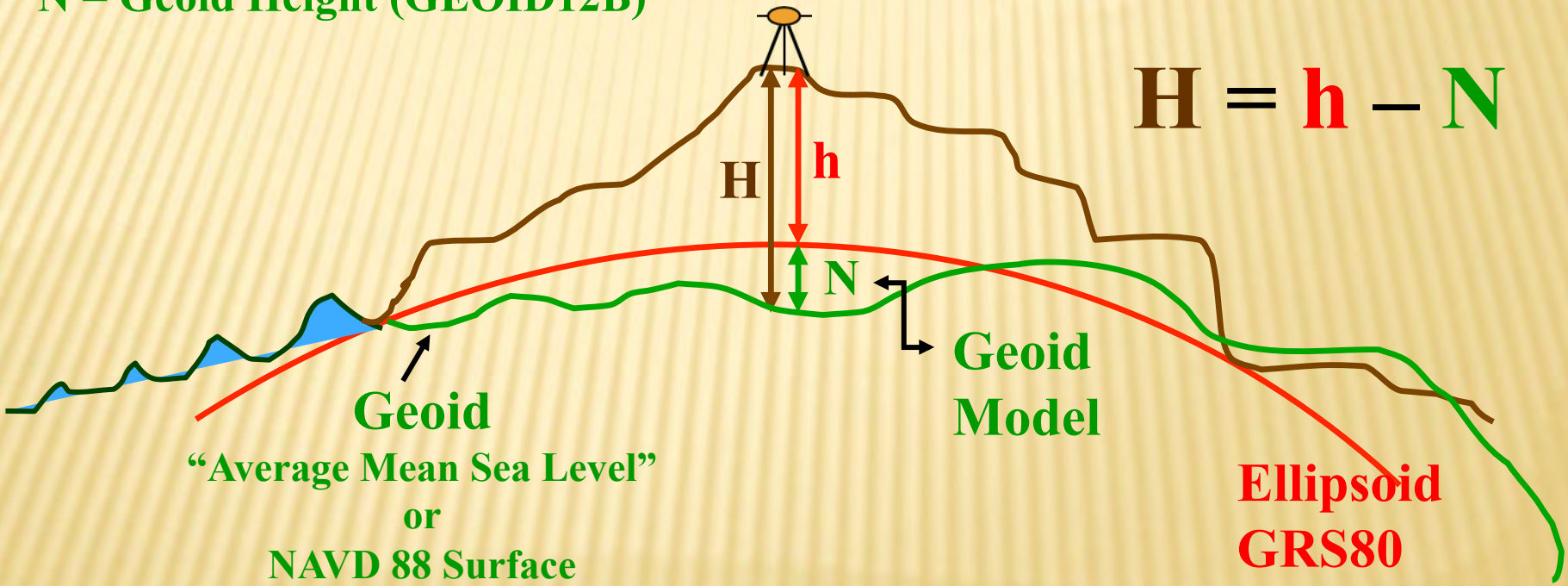

NAVD88
The North American Vertical Datum of 1988 is referenced to a single tide gauge in Canada
Prince Rupert
Vancover
Anacortes
Seattle
Fort Stephens
San Francisco
San Pedro
San Diego
Galveston
Biloxi
Pensacola
Fernandina Beach
Brunswick
St. Augustine
Cedar Keys
Father's Point
Halifax
Yarmouth
Portland
Boston
Perth Amboy
Atlantic City
Baltimore
Annapolis
Norfolk
Old Point Comfort
© 2008 Europa Technologies
© 2008 Tele Atlas
Image NASA
Image © 2008 TerraMetrics
Google

ELLIPSOID – GEOID RELATIONSHIP

H = Orthometric Height (NAVD 88)

h = Ellipsoid Height (NAD 83 (2011))

N = Geoid Height (GEOID12B)



Types of NGS Geoid Models

Gravimetric (or Gravity) Geoid Height Models (USGG2012, USGG2009)

Defined by gravity data crossing the geoid

Refined by terrain models (DEM's)

Scientific and engineering applications

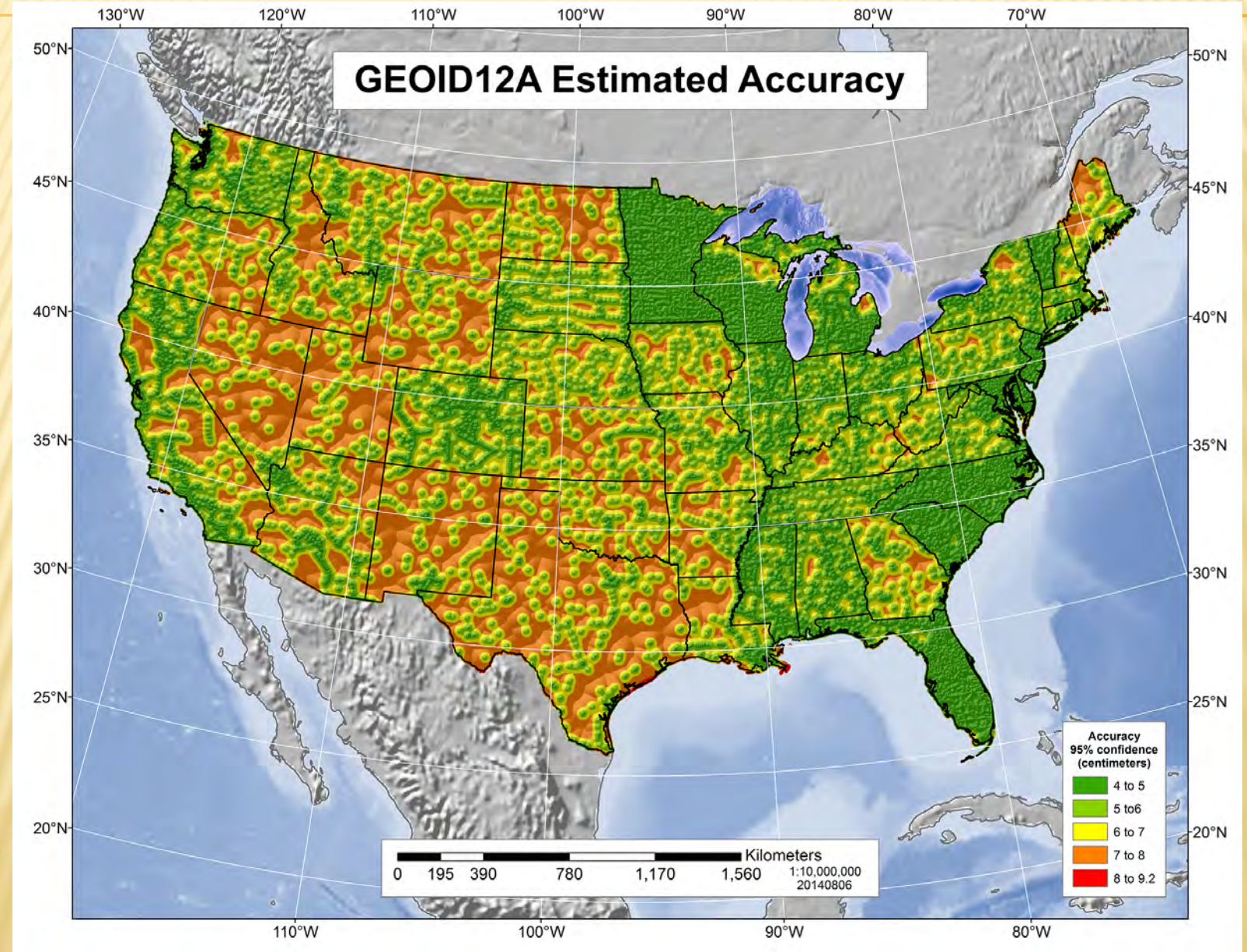
Composite (or Hybrid) Geoid Height Models (e.g. GEOID12A/B, GEOID09)

Starts with gravimetric geoid model

Warped to fit available GPS on BM control data

GEOID 12A/B ACCURACY

http://www.ngs.noaa.gov/web/surveys/GPSonBM/maps/GEOID12A_Accuracy.png



Metadata

Coordinates and heights without appropriate metadata have the same value as a boundary line in Google Earth

Just A Wild A Guess**

METADATA
Data About Data

DATUMS and REALIZATIONS

NAD 27, NAD 83(1986), NAD83 (199X),
NAD 83 (2007), NAD 83 (2011), Epoch xxxx.xx
NGVD29, NAVD88

UNITS

Meters, U.S. Survey Feet, International Feet

ACCURACY

A-Order, B-Order, 1st, 2nd, 3rd, 3cm, Scaled

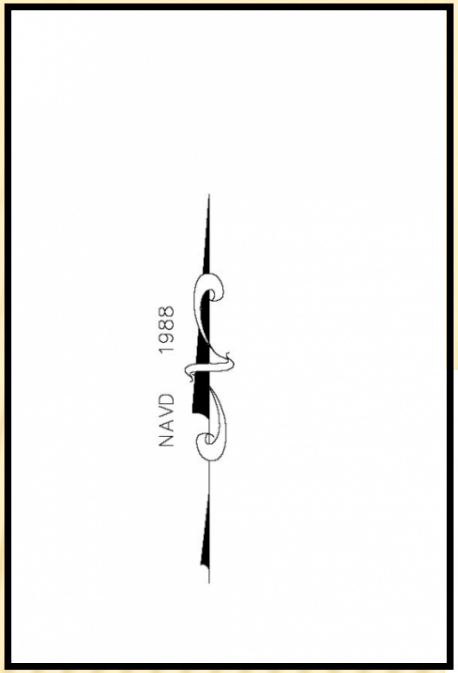
Examples of Bad Metadata

LEGEND:

- EXISTING CONTOURS
- EXISTING SANITARY SEWER
- EXISTING STORM DRAIN
- EDGE OF VEGETATION
- EXISTING STREET LIGHT
- EXISTING UTILITY POLE
- NEW CONTOURS
- MON-2 MONITORING POINT

MONITORING POINTS

POINT No.	NORTHING	EASTING	ELEV. (MLLW)
MON-1	708,407.42	1,178,660.64	16.91
MON-2	708,270.52	1,178,806.49	18.89
MON-3	708,133.66	1,178,952.30	19.14
MON-4	707,996.80	1,179,098.10	17.39
MON-5	707,859.83	1,179,243.87	18.00



SUPREME COURT OF THE UNITED STATES

No. 5 Orig.

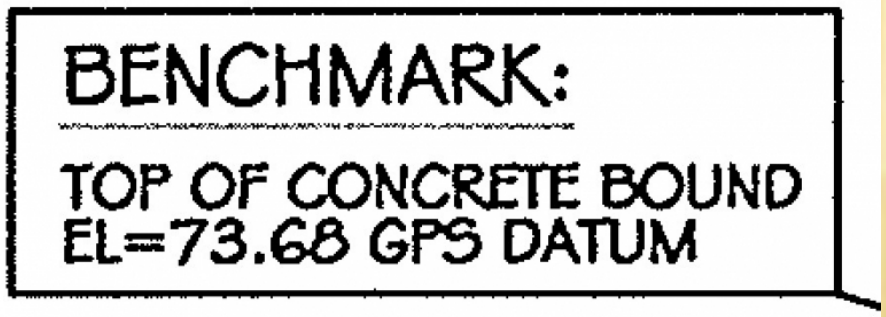
UNITED STATES OF AMERICA, PLAINTIFF *v.*
STATE OF CALIFORNIA

ON BILL OF COMPLAINT

[December 15, 2014]

Location of the Fixed Offshore Boundary Between the United States and California that is Parallel to the Coastline of Mainland California.

	NAD 83/WGS 84 UTM ZONE 11 (meters) x-coordinate	y-coordinate
BEGINNING AT	482577.890	3599275.555
BY ARC CENTERED AT	488133.576	3599216.475
TO	482623.800	3599931.673
BY STRAIGHT LINE TO	482614.890	3599955.433
BY ARC CENTERED AT	487607.655	3602392.938



Examples of Bad Metadata

```
        National Geodetic Survey,
 TV0474 ***********************************************************
 TV0474  DESIGNATION -  SUGAR
 TV0474  PID         -  TV0474
 TV0474  STATE/COUNTY-  VQ/ST JOHN
 TV0474  COUNTRY     -  US
 TV0474  USGS QUAD   -  WESTERN ST JOHN (1982)
 TV0474
 TV0474                      *CURRENT SURVEY CONTROL
 TV0474  ______________________________________________________________
 TV0474* NAD 83(1997) POSITION- 18 21 05.01515(N) 064 46 38.52774(W)   ADJUSTED
 TV0474
 TV0474  HORZ ORDER      -  THIRD

 TV0474'DESCRIBED BY COAST AND GEODETIC SURVEY 1918 (OWS)
 TV0474'STATION IS OLD STONE SUGAR FAN MILL ON KNOLL JUST W OF DENIS BAY
 TV0474'HOUSE.
```

Height from FEMA Flood Insurance Study = 159.6254 ft (!)
"Local Tidal Datum"
Which tidal datum? – MSL, MLLW, MHW?
What tidal datum epoch?

GOOD COORDINATION BEGINS WITH GOOD COORDINATES

GEOGRAPHY WITHOUT GEODESY IS A FELONY