

# Modernization of the National Spatial Reference System



***MALSCE***

**Massachusetts Association of Land Surveyors  
and Civil Engineers  
September 23, 2011**

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# Mission and Vision of NGS

- To define, maintain and provide access to the National Spatial Reference System to meet our nation's economic, social, and environmental needs
- "Maintain the NSRS" means "NGS must track all of the temporal changes to the defining points of the NSRS in such a way as to always maintain the accuracy in the NSRS definition."
- Vision - Modernize the Geopotential ("Vertical") and Geometric ("Horizontal") datums

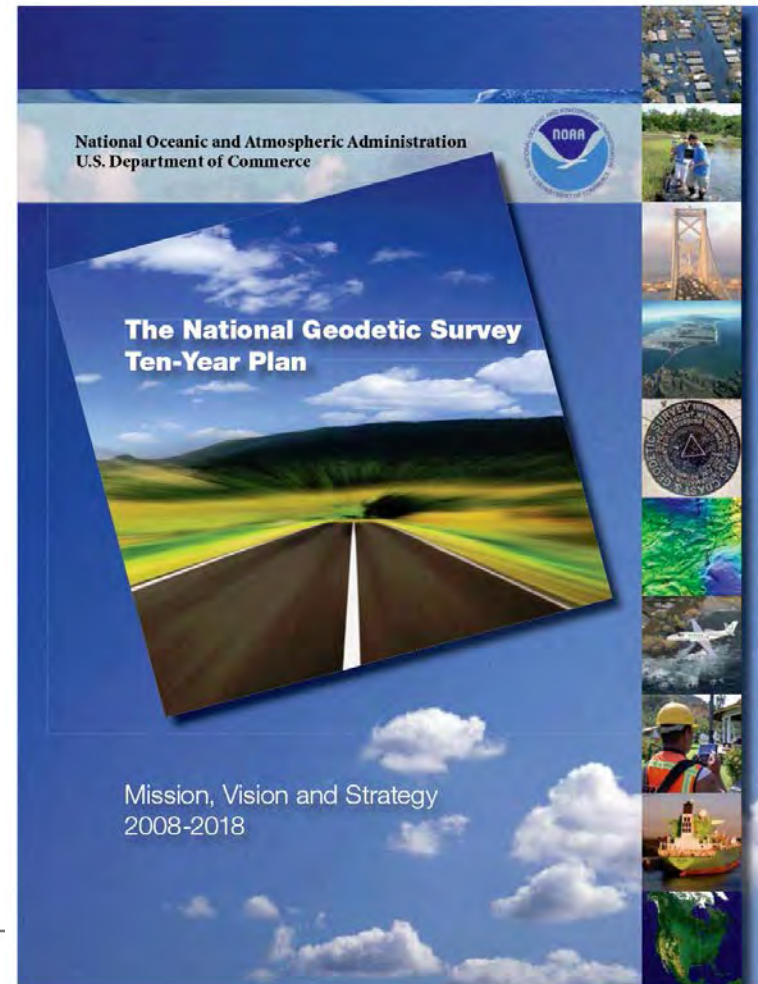
# Problems with NAD 83 and NAVD 88

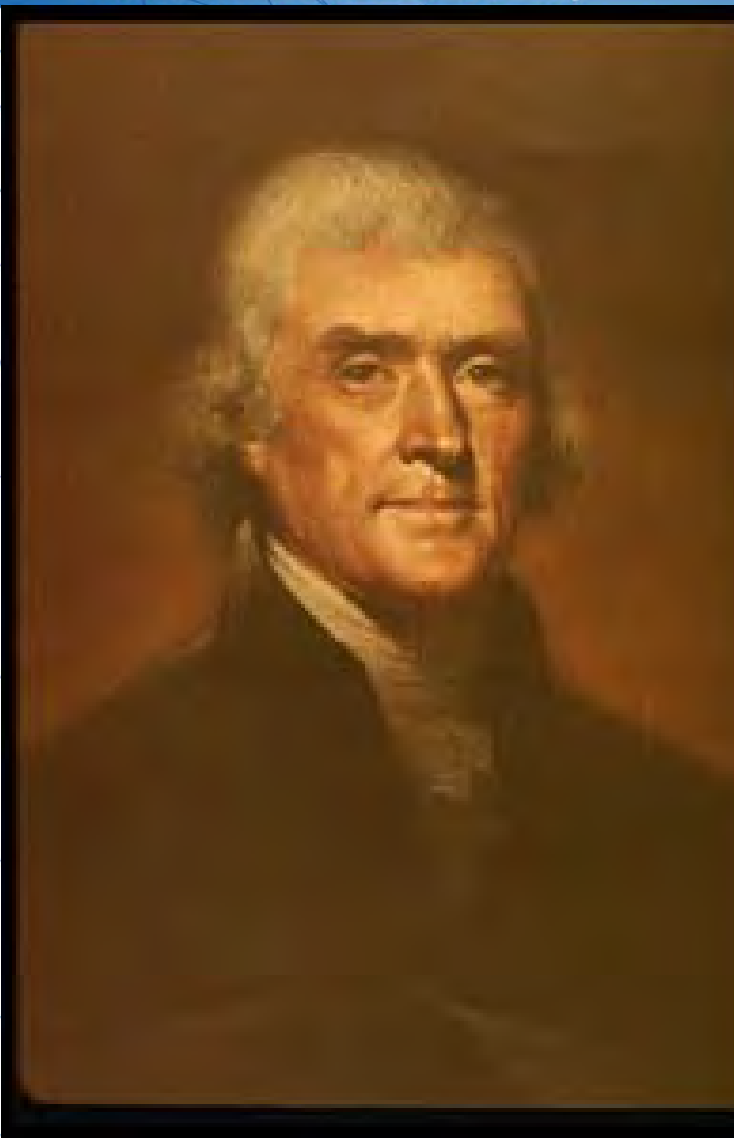
- ❖ **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - ❖ Surveyors don't see this - **Yet**
- ❖ **NAD 83** is not well defined with positional velocities
- ❖ **NAVD 88** is realized by passive control (bench marks) most of which have not been releveled in at least 40 years.
- ❖ **NAVD 88** does not account for local vertical velocities (subsidence and uplift)
  - ❖ Post glacial isostatic readjustment
  - ❖ Subsurface fluid withdrawal
  - ❖ Sediment loading
  - ❖ Sea level rise
    - ❖ Montauk – 2.8 mm/yr (0.01 ft/yr) Since 1947
    - ❖ Port Jefferson – 2.4 mm/yr (.01 ft/yr) Since 1957
    - ❖ Kings Point – 2.4 mm/yr (0.01 ft/yr) Since 1931
    - ❖ The Battery – 2.8 mm/yr (0.01 ft/yr) Since 1856
    - ❖ Sandy Hook, NJ – 3.9 mm/yr (0.01 ft/yr) Since 1932

# The National Geodetic Survey 10 year plan Mission, Vision and Strategy 2008 – 2018

<http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf>

- *Official NGS policy as of Jan 9, 2008*
  - *Modernized agency*
  - *Attention to accuracy*
  - *Attention to time-changes*
  - *Improved products and services*
  - *Integration with other fed missions*
- *2018 Targets: (now 2022)*
  - *NAD 83 and NAVD 88 re-defined*
  - *Cm-accuracy access to all coordinates*
  - *Customer-focused agency*
  - *Global scientific leadership*





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 distance 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 moneys in the treasury, not otherwise appropriated.

W. M. W. Speaker of the House of Representatives

W. M. W. Vice President of the United States, and President of the Senate.

February 10, 1807

Approved

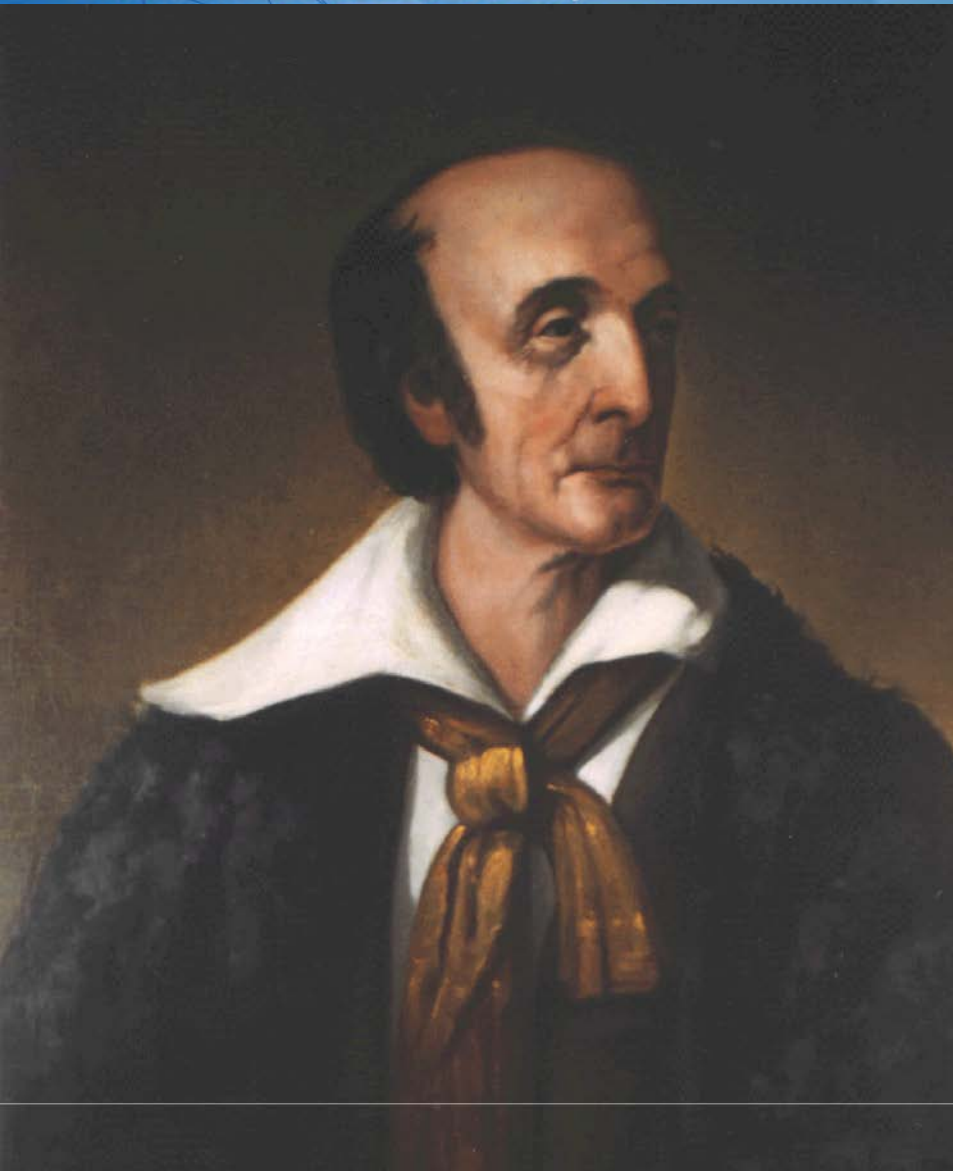
Jefferson

Proved, that this act did originate in the House of Representatives.

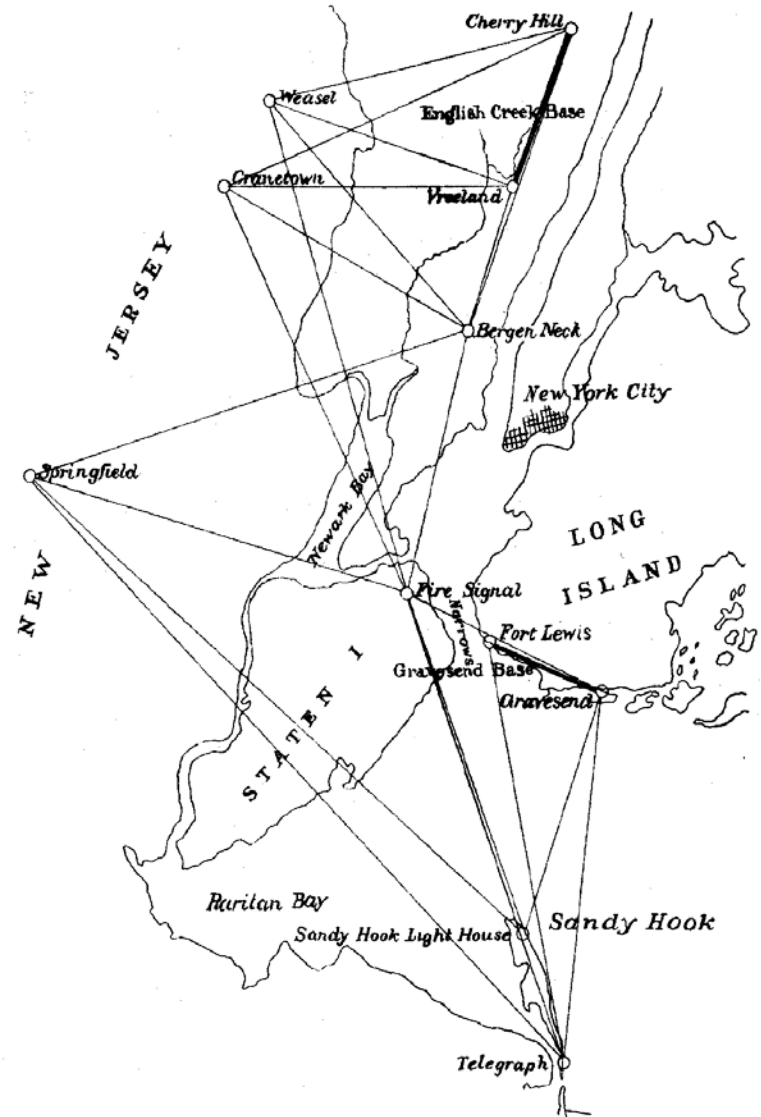
John Breckinridge Clerk

1807

President Thomas Jefferson signs legislation establishing the Survey of the Coast



Ferdinand Hassler (1770-1843)



Hassler's First Field Work, 1816-1817



# 1984

## An End of an Era





**Global Satellite Triangulation Network  
1964-1973**



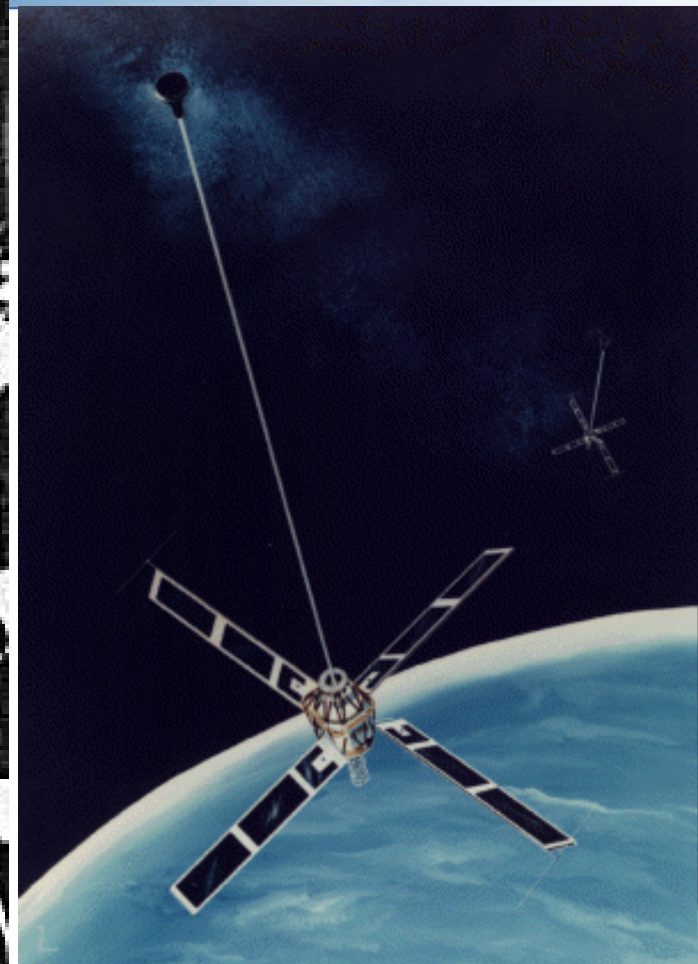
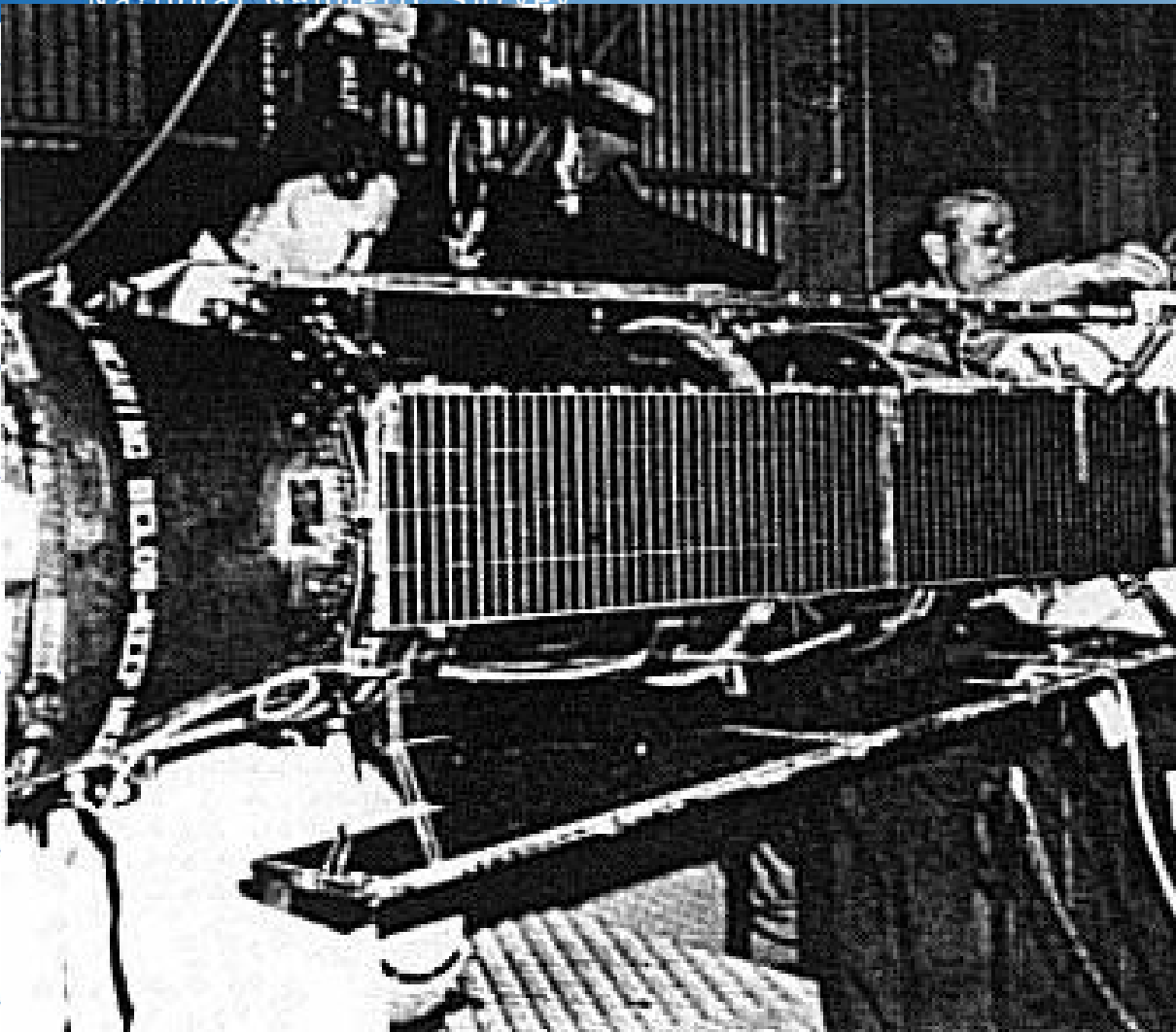


**ECHO/PAGEOS Balloon Satellite**  
National Oceanic and Atmospheric Administration  
**type of satellite photographed by BC-4**



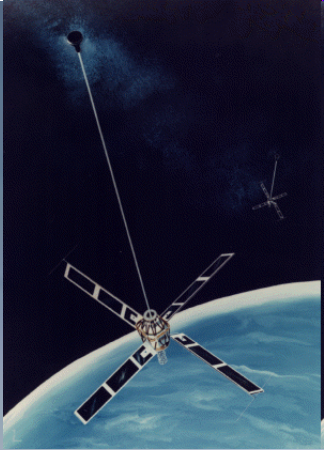


BC-4 camera photograph  
stars in circular pattern  
satellite is a series of dots in straight line.



## US Navy Transit Satellite 1964 (Military), 1967 (Civilian)

# DOPPLER and VLBI



# The NSRS has evolved



1 Million  
Monuments  
(Separate Horizontal  
and Vertical Systems)

70,000  
Passive Marks  
(3-Dimensional)



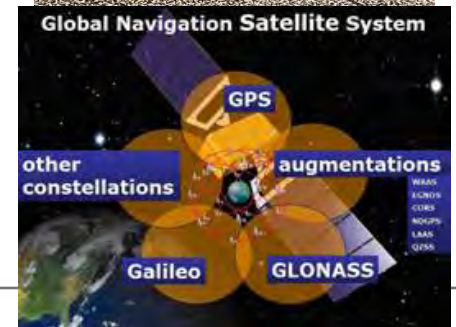
Passive  
Marks  
(Limited  
Knowledge of  
Stability)



1,693 GPS  
CORS  
(Time Dependent  
System Possible;  
4-Dimensional)



GPS CORS → GNSS CORS



# GEODETIC DATUMS

## HORIZONTAL

2 D (Latitude and Longitude) (e.g. NAD 27, NAD 83 (1986))

## VERTICAL

1 D (Orthometric Height) (e.g. NGVD 29, NAVD 88, Local Tidal)

## GEOMETRIC

3 D (Latitude, Longitude and Ellipsoid Height)  
Fixed and Stable - Coordinates seldom change  
(e.g. NAD 83 (1996), NAD 83 (2007), NAD 83 (CORS96))

also

4 D (Latitude, Longitude, Ellipsoid Height, Velocities) Coordinates change  
with time  
(e.g. ITRF00, ITRF08)



# International Earth Rotation and Reference System Service (IERS)

<http://www.iers.org>

The International Terrestrial Reference System (**ITRS**) constitutes a set of prescriptions and conventions together with the modeling required to define origin, scale, orientation and time evolution

ITRS is realized by the International Terrestrial Reference Frame (**ITRF**) based upon estimated coordinates and velocities of a set of stations observed by Very Long Baseline Interferometry (**VLBI**), Satellite Laser Ranging (**SLR**), Global Positioning System and GLONASS (**GNSS**), and Doppler Orbitography and Radio- positioning Integrated by Satellite (**DORIS**).

**ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97,  
ITRF2000, ITRF2005, ITRF2008**



# International Terrestrial Reference Frame

## 4 Global Independent Positioning Technologies





# History of vertical datums in the USA

- **Pre-National Geodetic Vertical Datum of 1929 (NGVD 29)**
  - The first geodetic leveling project in the United States was surveyed by the Coast Survey from 1856 to 1857.
  - Transcontinental leveling commenced from Hagerstown, MD in 1877.
  - General Adjustments of leveling data yielded datums in 1900, 1903, 1907, and 1912. (Sometimes referenced as the Sandy Hook Datum)
  - NGS does not offer a utility which transforms from these older datums into newer ones (though some users still work in them!)

# History of vertical datums in the USA

- **NGVD 29**

- National Geodetic Vertical Datum of 1929
- Original name: “Sea Level Datum of 1929”
- “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



# History of vertical datums in the USA

- **NAVD 88**

- North American Vertical Datum of 1988
- One height held fixed at “Father Point” (Rimouski, Canada)
- ...height chosen was to minimize 1929/1988 differences on USGS topo maps in the eastern U.S.
- Thus, the “zero height surface” of NAVD 88 wasn’t chosen for its closeness to the geoid (but it was close...few decimeters)

# History of vertical datums in the USA

- **NAVD 88** (continued)
  - 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
  - But 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

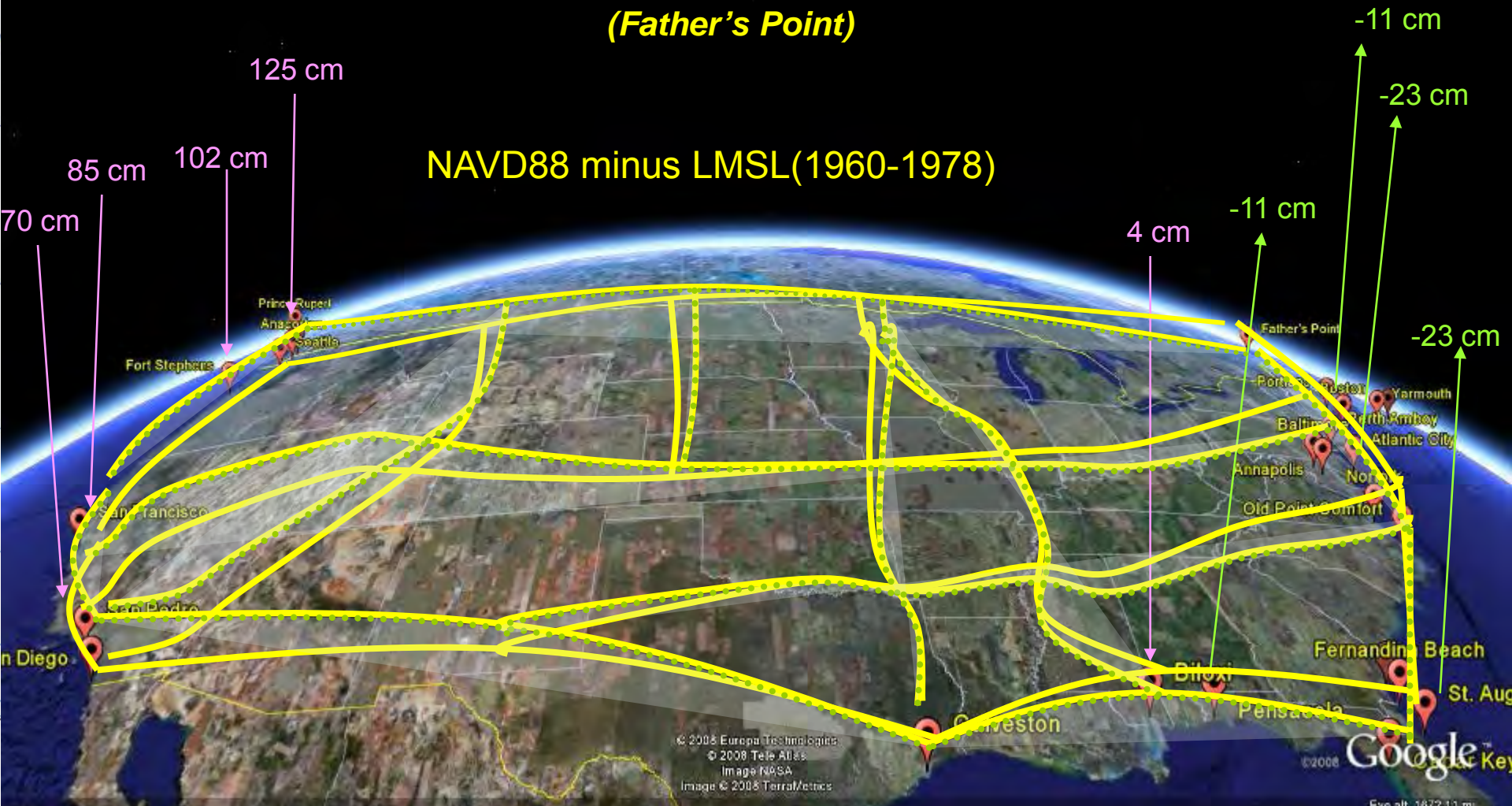


# NAVD 88

Reference to 26 Tide Gages

(Father's Point)

NAVD88 minus LMSL(1960-1978)



## Problems using traditional leveling (to define a National Vertical Datum)

- Leveling the country can not be done again
  - Too costly in time and money (Estimated ~ \$1B)
- Leveling yields cross-country error build-up; problems in the mountains
- Leveling requires leaving behind passive marks
  - Bulldozers and crustal motion do their worst




# Why isn't NAVD 88 good enough anymore

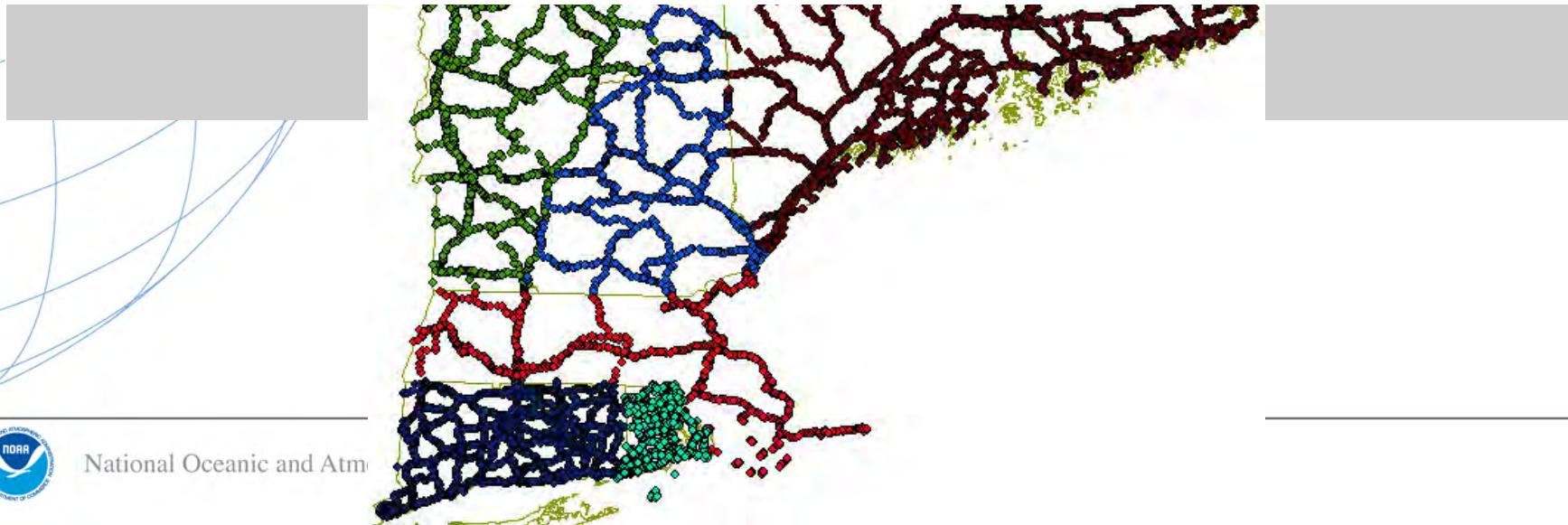
- **NAVD 88 suffers from use of bench marks that:**
  - Are almost never re-checked for movement
  - Disappear by the thousands every year
  - Are not funded for replacement
  - Are not necessarily in convenient places
  - Don't exist in most of Alaska
  - Weren't adopted in Canada
  - Were determined by leveling from a single point, allowing cross-country error build up

# Why isn't NAVD 88 good enough anymore?

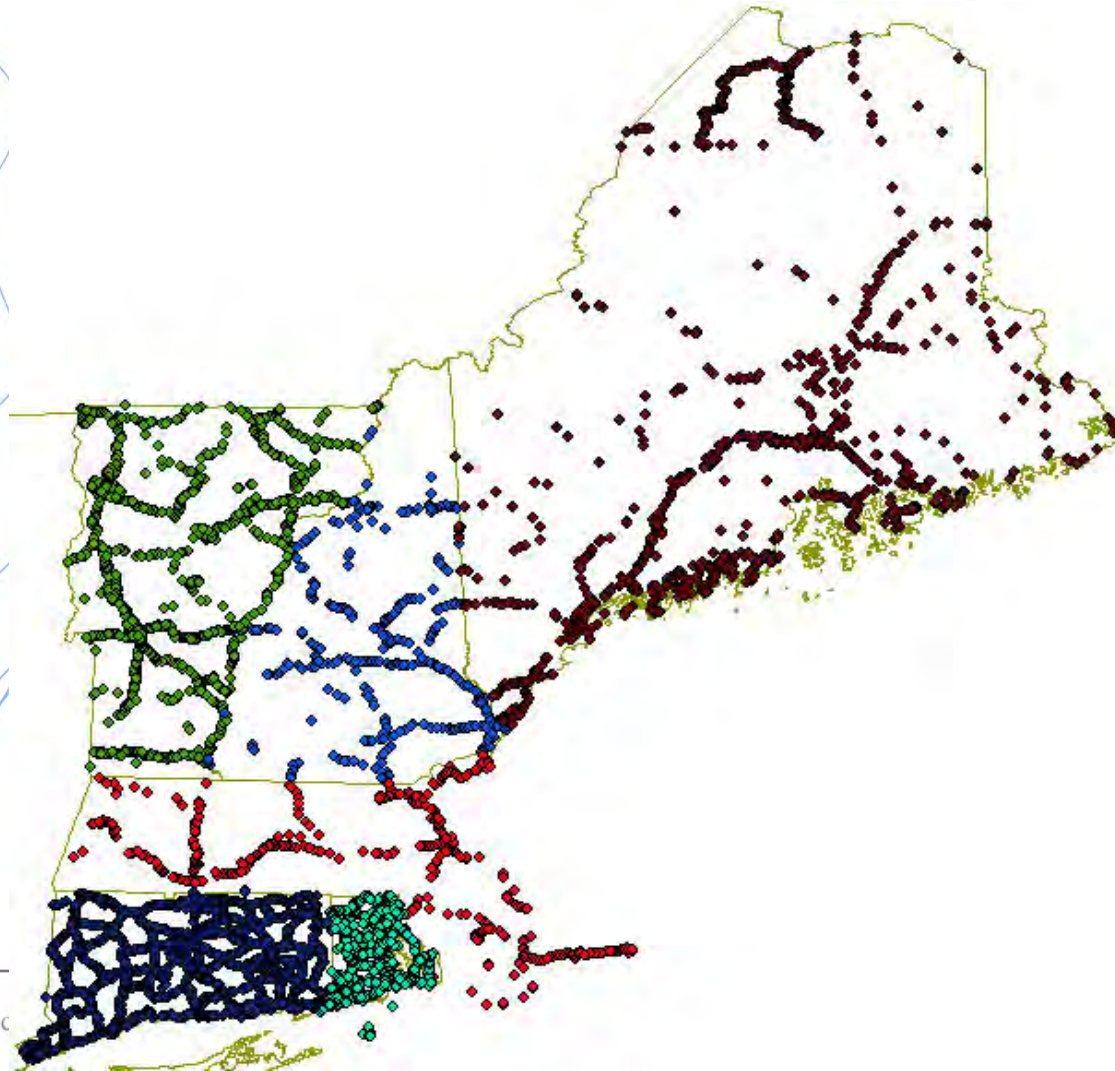
- **NAVD 88 suffers from:**
- A zero height surface that:
  - Has been proven to be ~50 cm biased from the latest, best geoid models (GRACE satellite)
  - Has been proven to be ~ 1 meter tilted across CONUS (again, based on the independently computed geoid from the GRACE satellite)

# NGSIDB BM Status (1<sup>st</sup>, 2<sup>nd</sup> order)

	CT	MA	ME	NH	RI	VT
In NSIDB	2599	1125	5401	1092	1380	2158
						



# NE Vertical Control



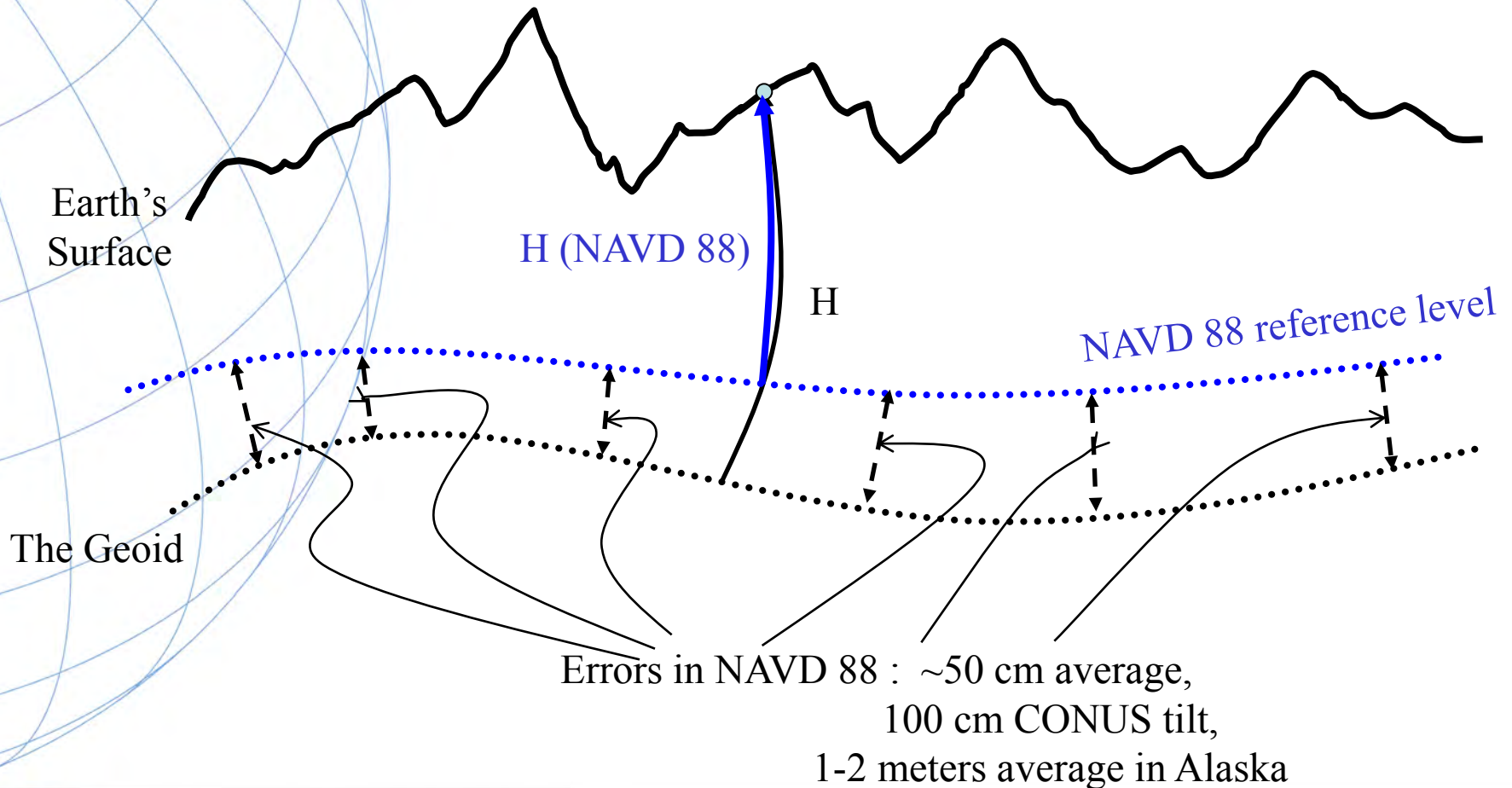
# Height-Mod means More Marks

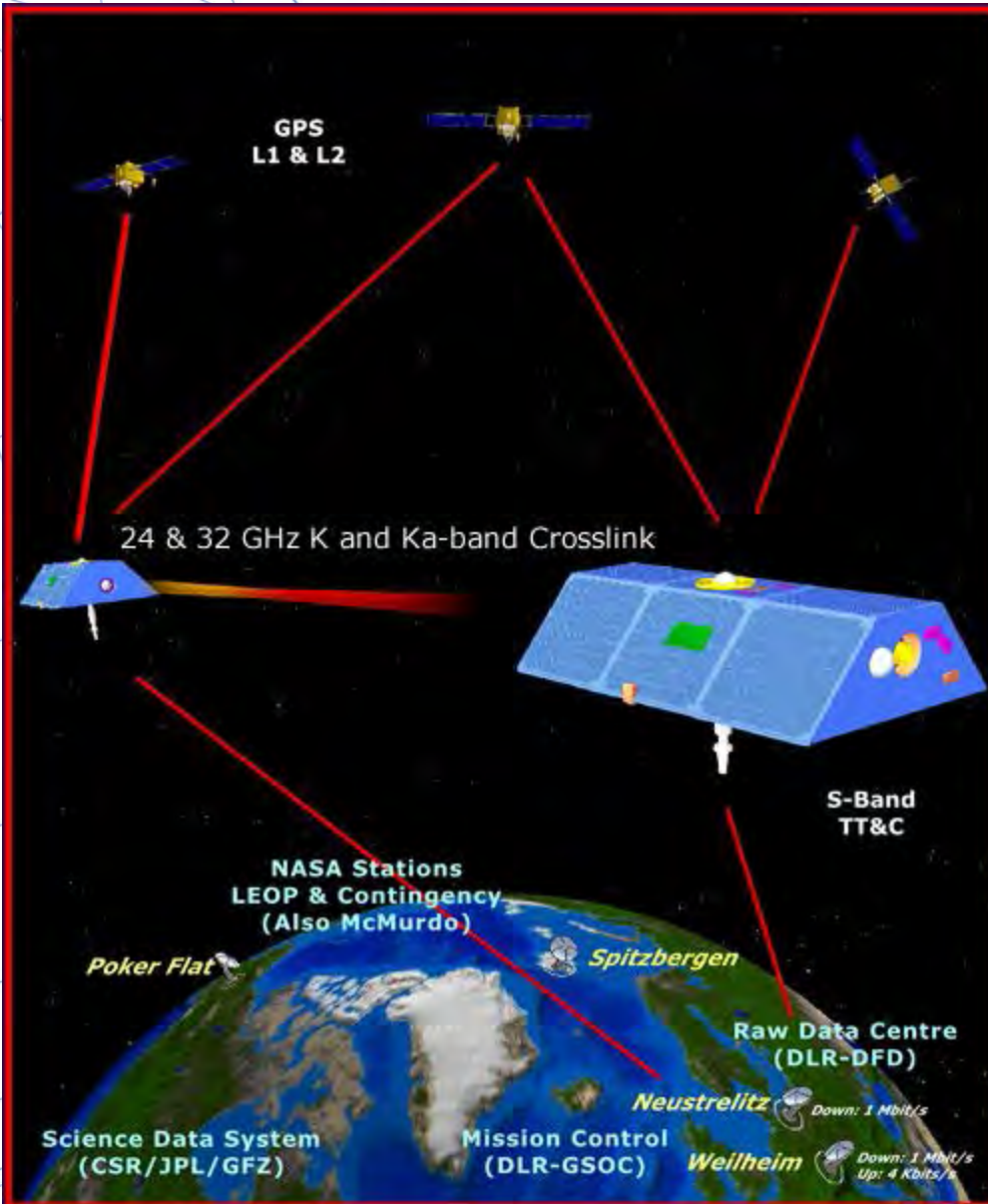


# Height Modernization Bottom line

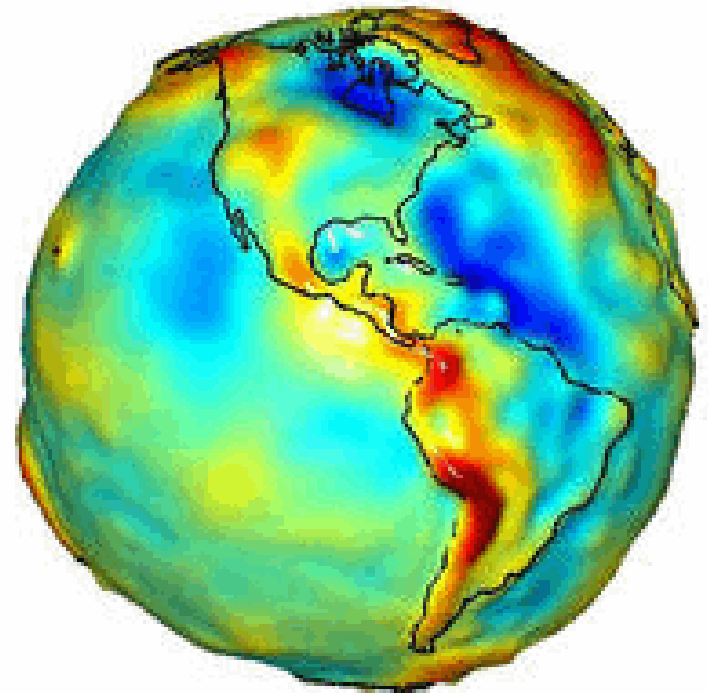
- 1. Using GNSS is cheaper, easier than leveling**
- 2. To use GNSS we need a good geoid model**

# Why isn't NAVD 88 good enough anymore?





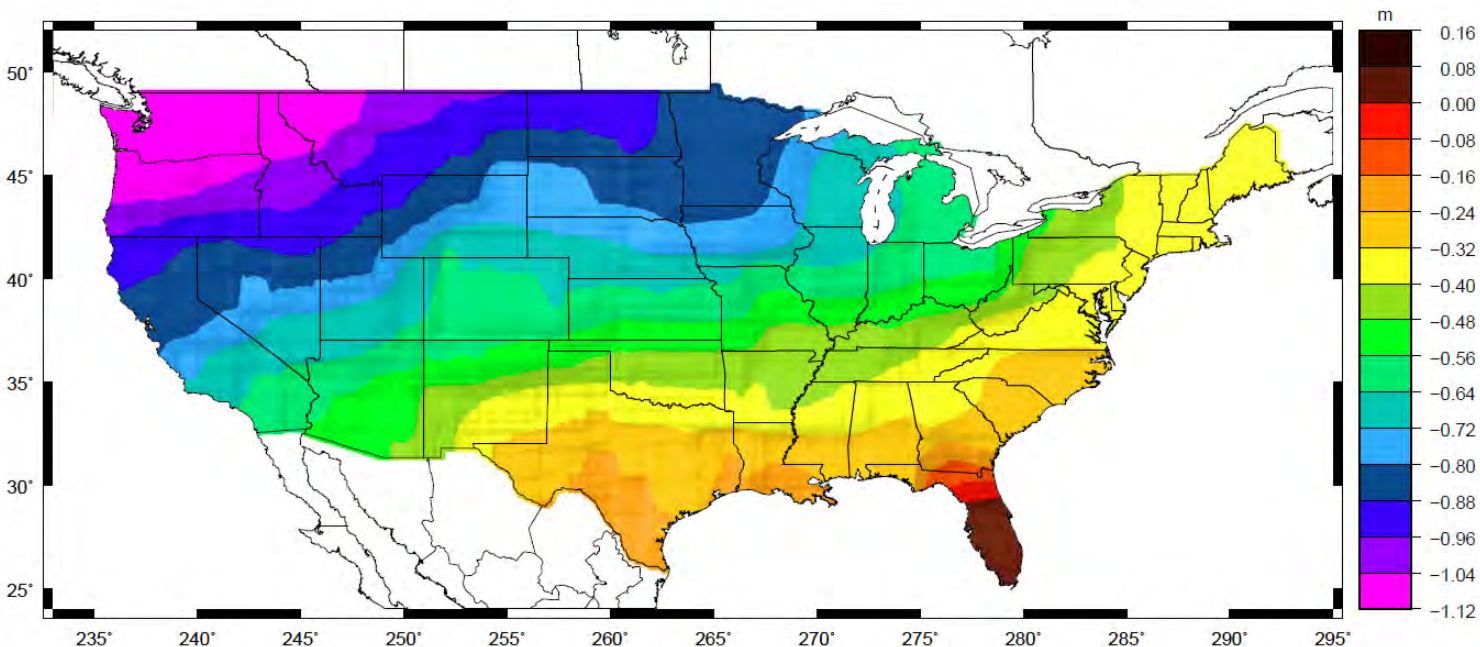
## GRACE – Gravity Recovery and Climate Experiment





# Why isn't NAVD 88 good enough anymore?

- Approximate level of geoid mismatch known to exist in the NAVD 88 zero

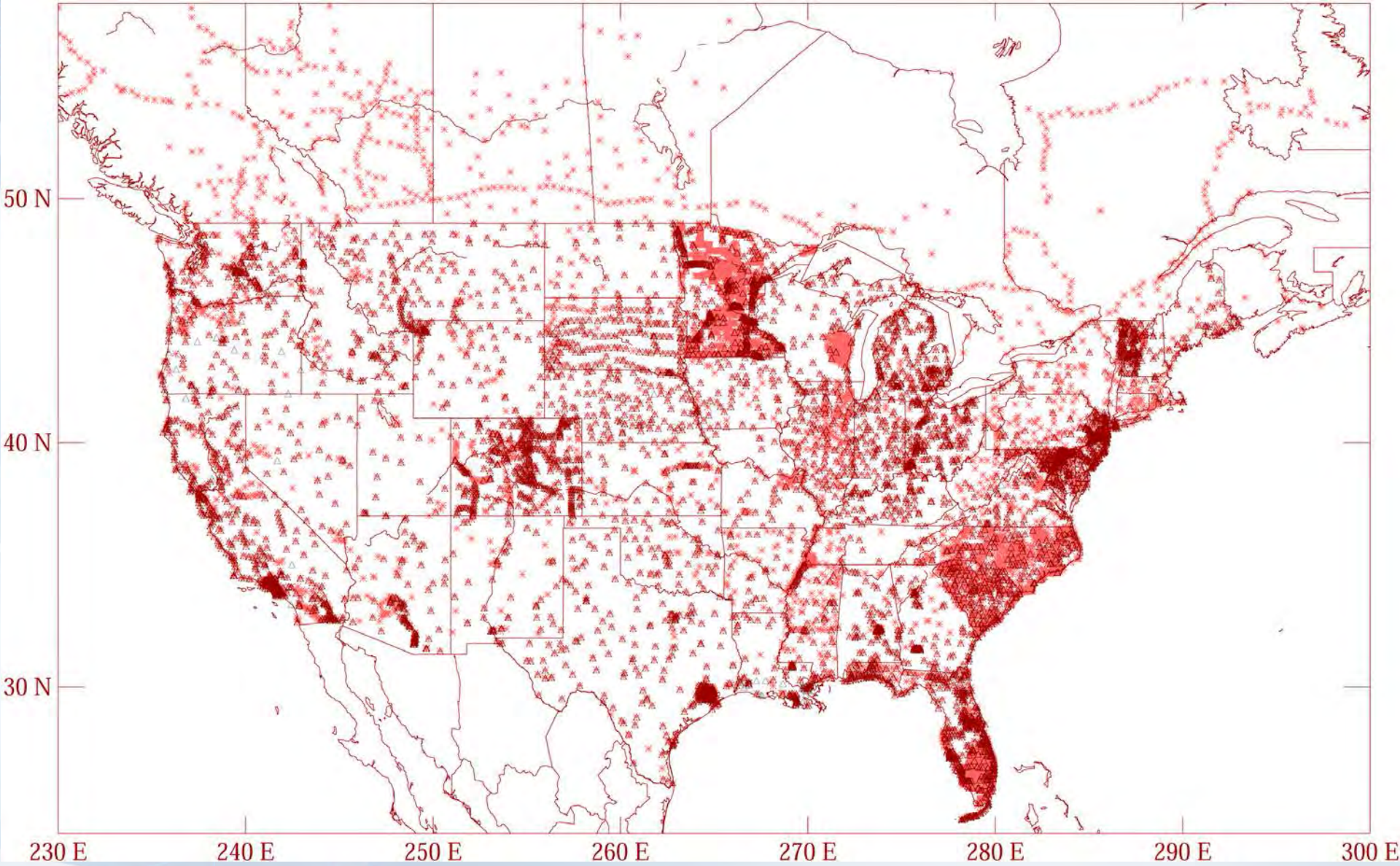


# How accurate is a GPS-derived Orthometric Height?

- Relative (local) accuracy in ellipsoid heights between adjacent points can be better than 2 cm, at 95% confidence level
- Network accuracy (relative to NSRS) in ellipsoid heights can be better than 5 cm, at 95% confidence level
- Accuracy of orthometric height is dependent on accuracy of the geoid model – Currently NGS is improving the geoid model with more data, i.e. Gravity and GPS observations on leveled bench marks from Height Mod projects
- Geoid09 can have an uncertainty in the 2-5 cm range.

# Types and Uses of Geoid Height Models

- Gravimetric (or Gravity) Geoid Height Models
  - Defined by gravity data crossing the geoid
  - Refined by terrain models (DEM's)
  - Scientific and engineering applications
- Composite (or Hybrid) Geoid Height Models
  - Gravimetric geoid defines most regions
  - Warped to fit available GPSBM control data
  - Defined by legislated ellipsoid (NAD 83) and local vertical datum (NAVD 88, PRVD02, etc.)
  - May be statutory for some surveying & mapping applications

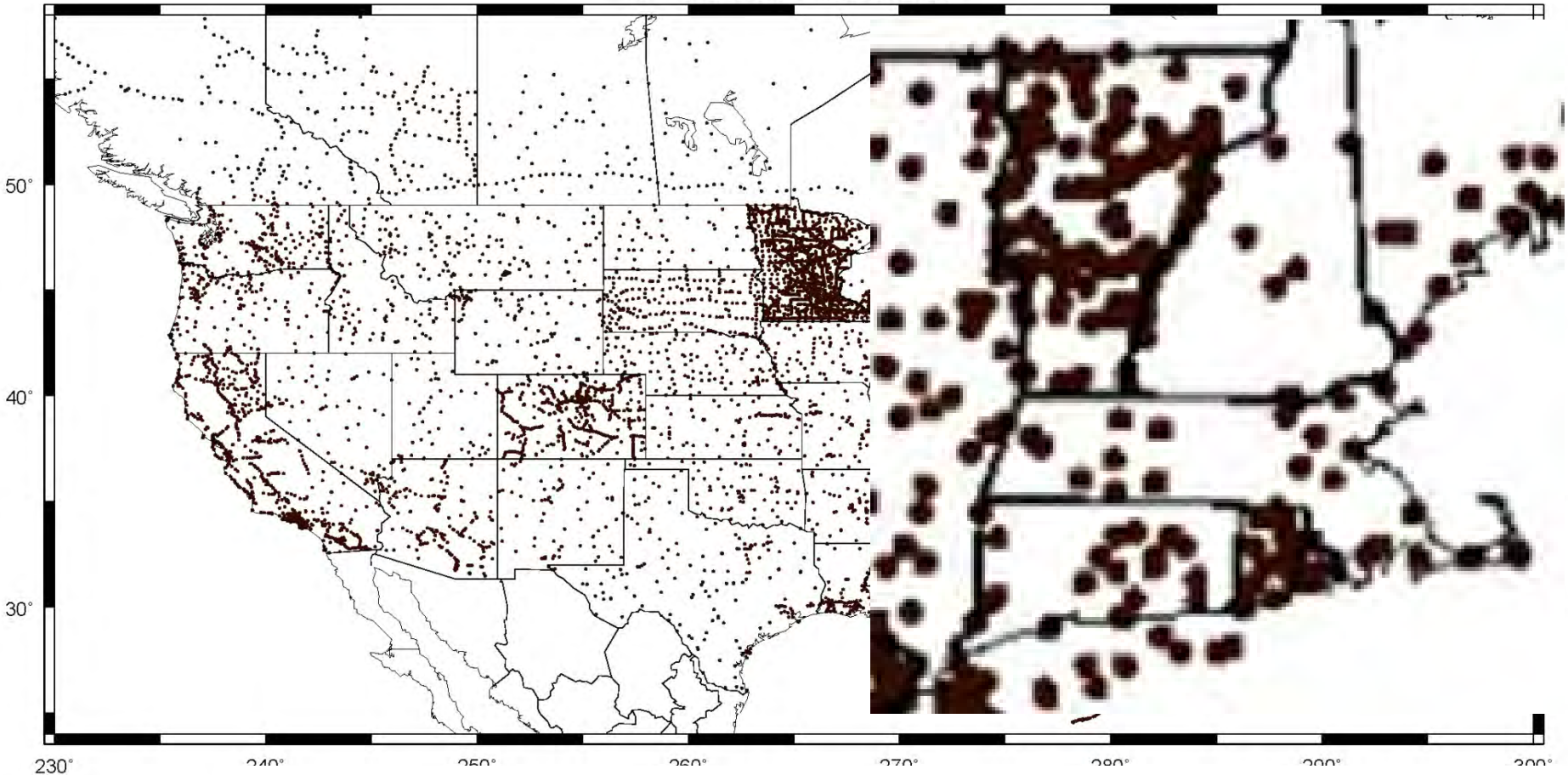


GGPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm ( $2\sigma$ )

GGPSBM2003: 14,185 total 579 Canada STDEV 4.8 cm ( $2\sigma$ )



GPS BMs for GEOID09

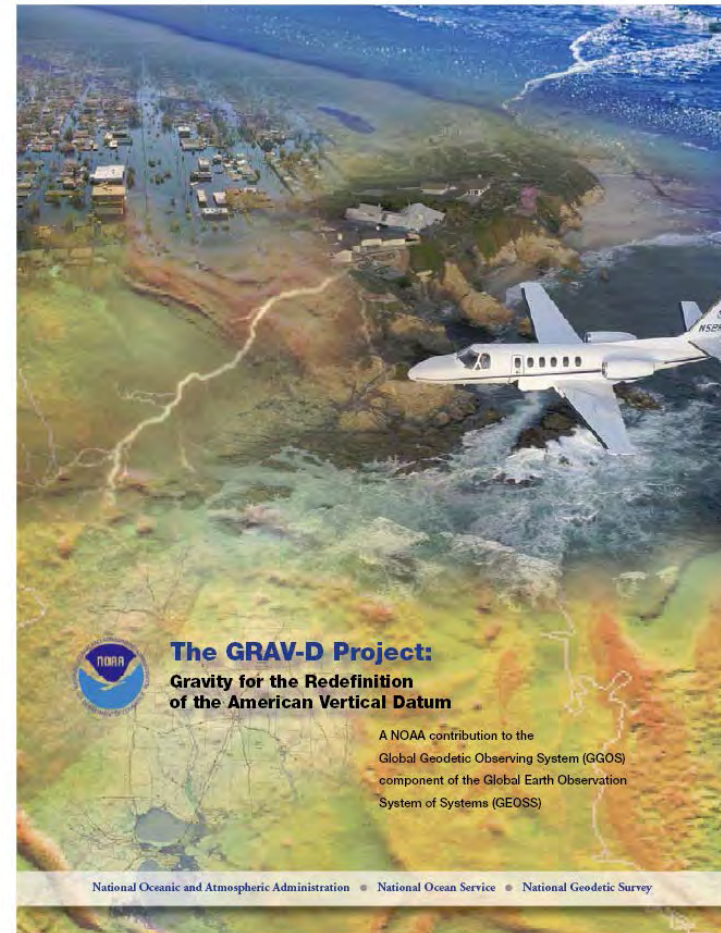


GGPSBM2009: 18,398 STDEV 2.8 cm ( $2\sigma$ )

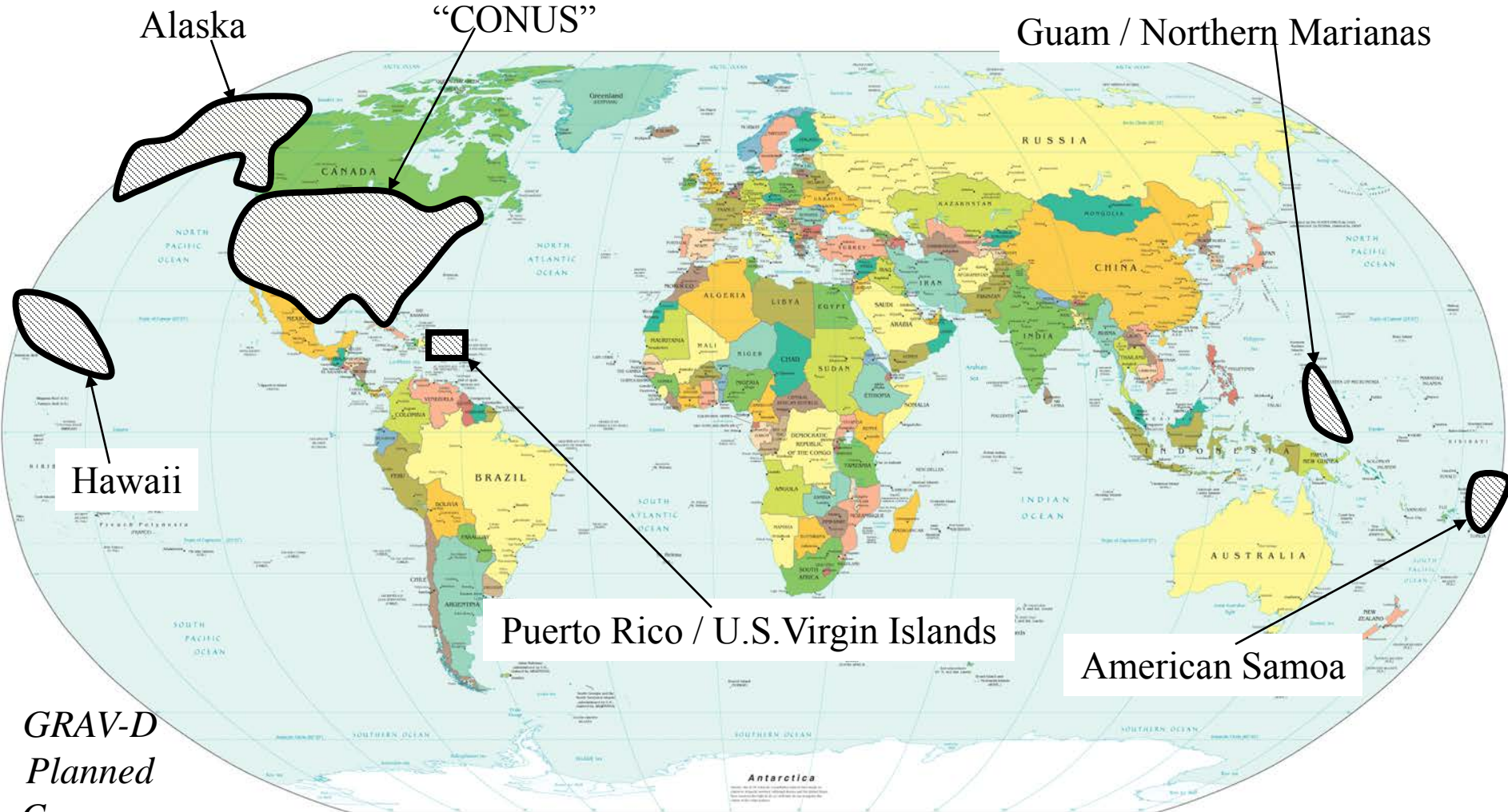
# Transition to the Future – GRAV-D

## Gravity for the Redefinition of the American Vertical Datum

- Official NGS policy as of Nov 14, 2007
  - \$38.5M over 10 years
- Airborne Gravity Snapshot
- Absolute Gravity Tracking
- Re-define the Vertical Datum of the USA by 2018  
(2022 more likely due to funding issues)



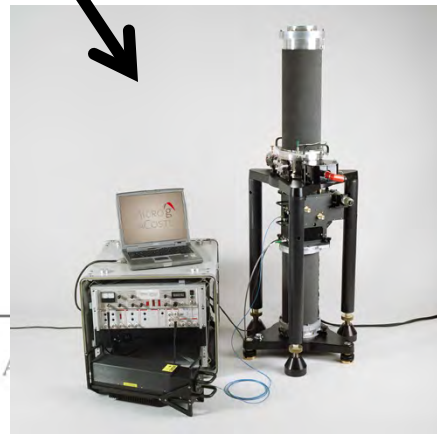
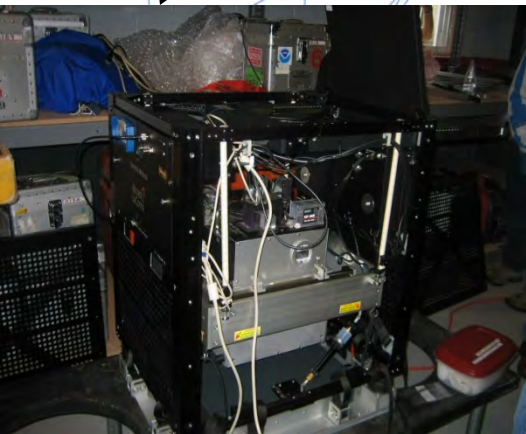
# What is GRAV-D?



*GRAV-D  
Planned  
Coverage*

# Gravity Survey Plan

- National Scale Part 1
  - Predominantly through airborne gravity
  - With Absolute Gravity for ties and checks
  - Relative Gravity for expanding local regions where airborne shows significant mismatch with existing terrestrial





# What is GRAV-D?

- **GRAV-D will mean:**
  - As the  $H=0$  surface, the geoid will be tracked over time to keep the datum up to date
  - The reliance on passive marks will dwindle to:
    - Secondary access to the datum
    - Minimal NGS involvement
      - Maintenance/checking in the hands of users
    - Use at your own risk

# CONTINUOUSLY OPERATING REFERENCE STATIONS (CORS)

**1693 Installed and Operated by  
various Federal-State-local Agencies**

**NOAA/National Geodetic Survey**

**NOAA/OAR Global Systems Division**

**U.S. Coast Guard - DGPS/NDGPS**

**Corps of Engineers - DGPS**

**FAA - WAAS/LAAS**

**State DOTs**

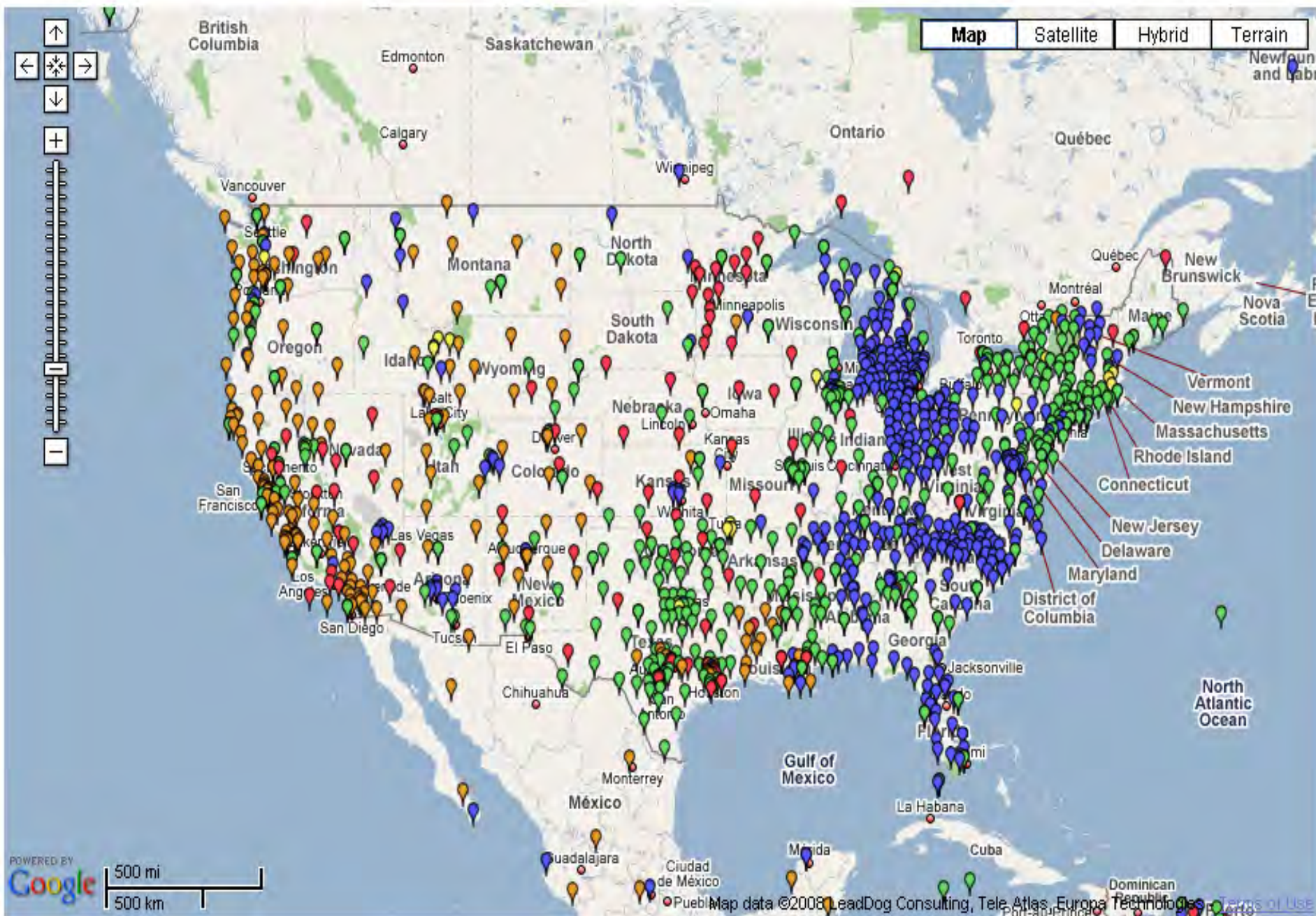
**County and City**

**Academia**

**Private Companies**



1 sec 5 sec 10 sec 15 sec 30 sec All Decommissioned



POWERED BY Google  
500 mi  
500 km

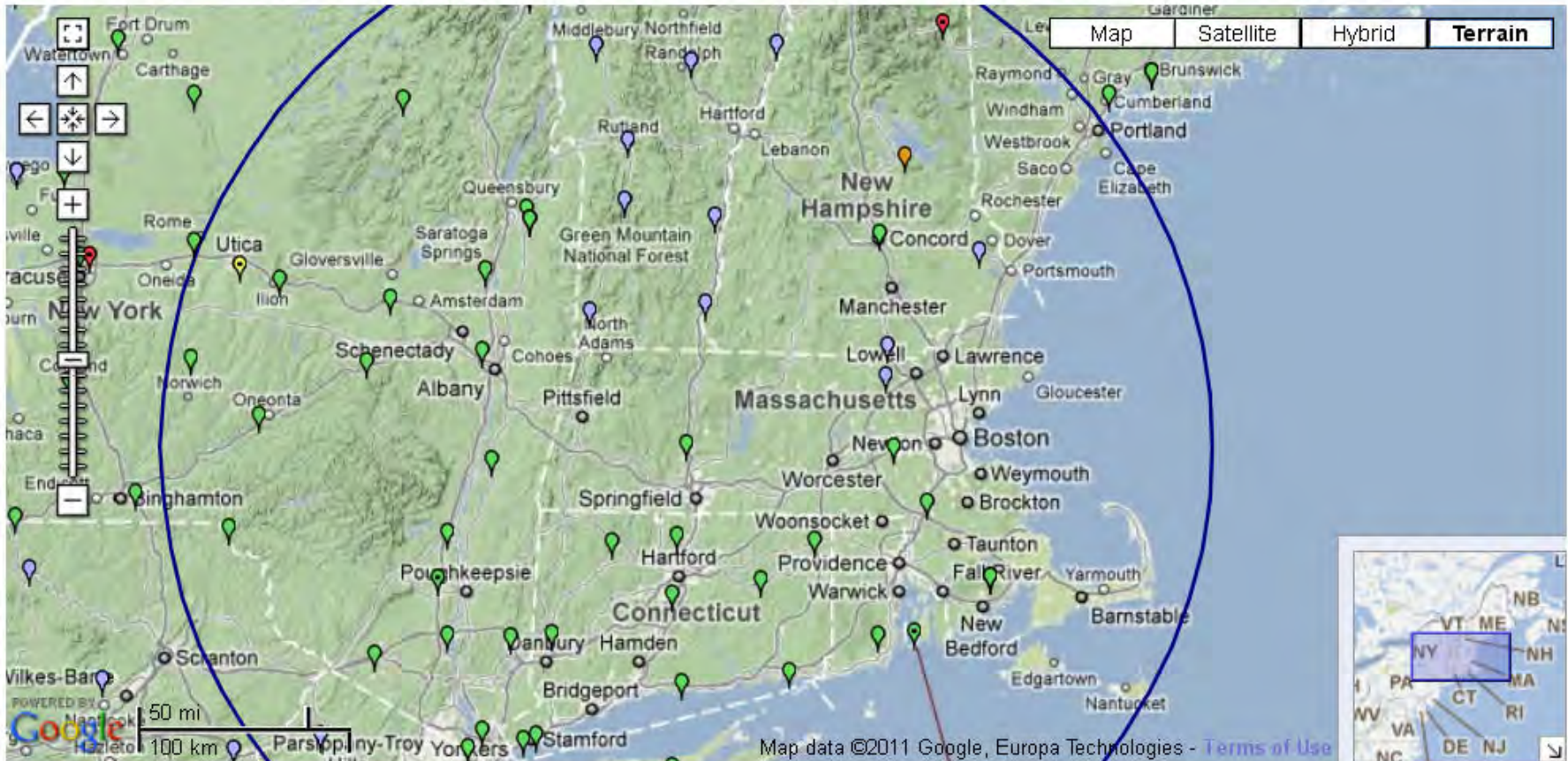
Map data ©2008 LeadDog Consulting, Tele Atlas, Europa Technologies, Terms of Use

# REGIONAL CORS NETWORK

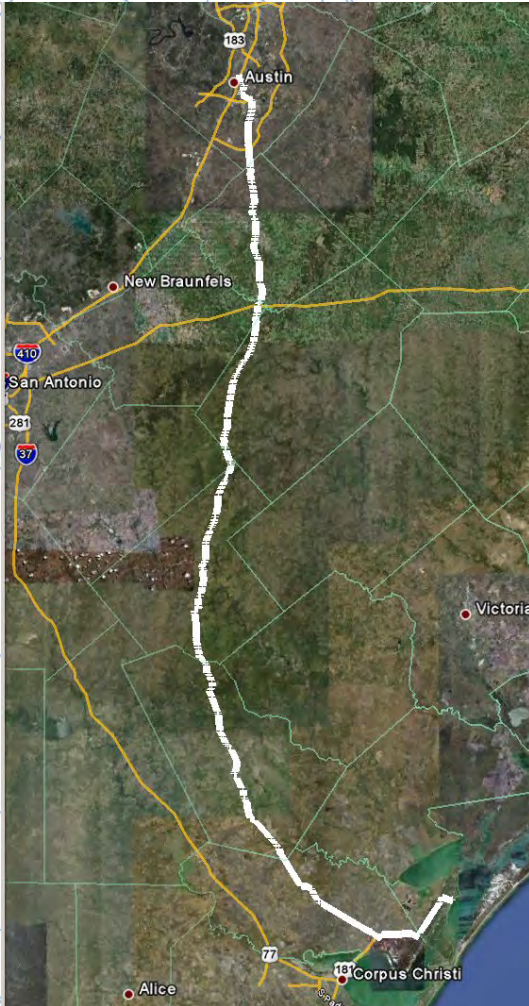
Sampling Rate (clickable legend icons)

- 1 sec
- 5 sec
- 10 sec
- 15 sec
- 30 sec
- All Active
- Decom

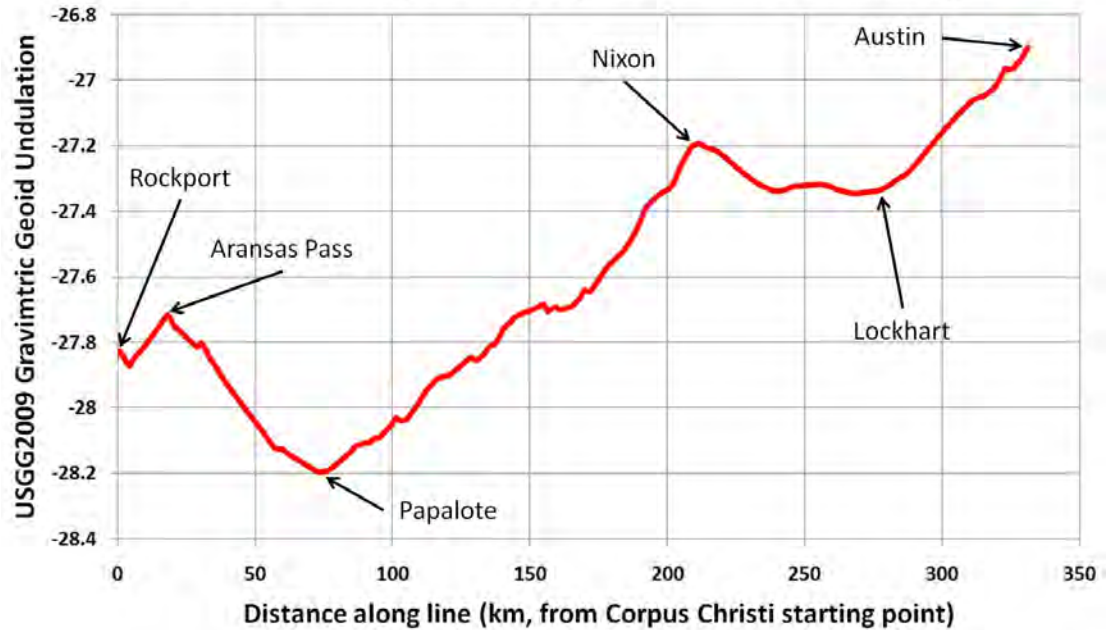
Non-Operational 250 km radius



# Geoid Slope Validation Survey of 2011 GSVS11



### USGG2009 Gravimetric Geoid Slope along GSVS11 Survey Line (Corpus Christi to Austin)



# GSVS11 Components

- Differential Leveling
- Campaign GPS
- RTN-based GPS
- Absolute Gravity
- Gravity Gradients
- Deflections of the Vertical
- Airborne LIDAR
- Airborne Imagery



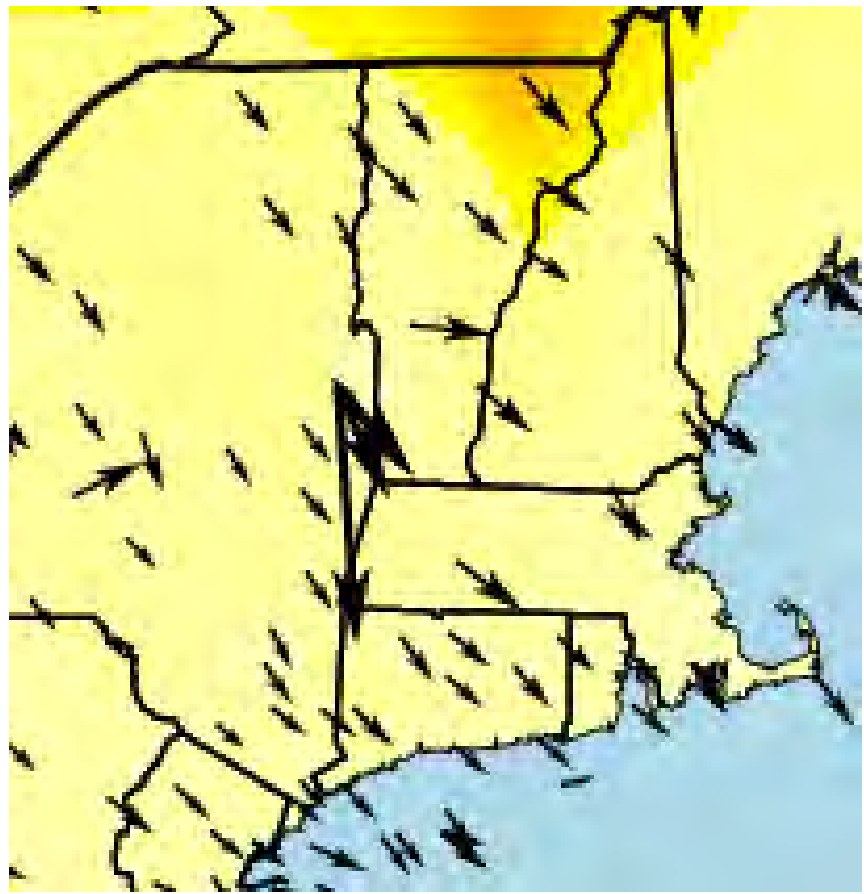
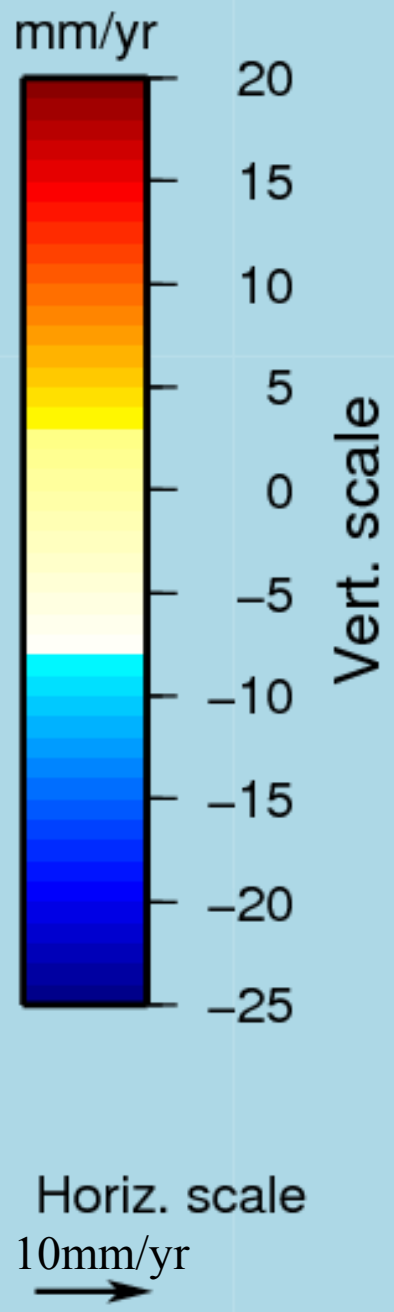
# CORS Multi-Year Adjustment NAD 83(2011) epoch 2010.0 – Why???

- Mixed coordinates from an earlier solution (1994-2002) that used only 3-8 ITRF reference frame sites to align to the global frame
- Mixed horizontal velocities: modeled from HTDP vs. computed
- Mixed vertical velocities, which for many of the NAD 83(COR96,MARP00,PACP00) epoch 2002.00 stations are assigned a value of 0 mm/yr
- NGS's current global frame is ITRF00 epoch 1997.00; projecting positions 13 years to the present is unrealistic
- NGS's current plate-fixed frame is NAD 83(CORS96,MARP00,PACP00) epoch 2002.00; projecting positions 8 years to the present is also questionable
- Implementing significant changes to existing processing algorithms and models including compliance with IERS conventions (i.e. software changes)
- Switching from using relative antenna calibration to absolute antenna calibrations
- The current state-of-the-art full (~230 stations) global reference frame: IGS08 epoch 2005.00
- Given these major inconsistencies and changes, NGS elected to reprocess all its CORS data to provide a single consistent set of coordinates for all sites computed using the best available methods.





# NAD 83 (2011) Velocity



\*\*\*IGS 08\*\*\*

MTS FRAM COOP (FMTS), MASSACHUSETTS

Created on 31Aug2011 at 09:58:47.

Antenna Reference Point(ARP): MTS FRAM COOP CORS ARP

-----  
PID = DI0964

## IGS08 POSITION (EPOCH 2005.0)

Computed in Aug 2011 using data through gpswk 1631.

X =	1503699.862 m	latitude	=	42 18 00.20488 N
Y =	-4478988.684 m	longitude	=	071 26 30.87477 W
Z =	4270342.559 m	ellipsoid height	=	42.829 m

## IGS08 VELOCITY

Predicted with HTDP\_3.1.2 Aug 2011.

VX =	-0.0157 m/yr	northward	=	0.0059 m/yr
VY =	-0.0010 m/yr	eastward	=	-0.0152 m/yr
VZ =	0.0043 m/yr	upward	=	-0.0001 m/yr

## NAD\_83 (2011) POSITION (EPOCH 2010.0)

Transformed from IGS08 (epoch 2005.0) position in Aug 2011.

X =	1503700.559 m	latitude	=	42 18 00.17158 N
Y =	-4478990.127 m	longitude	=	071 26 30.86597 W
Z =	4270342.616 m	ellipsoid height	=	44.044 m

## NAD\_83 (2011) VELOCITY

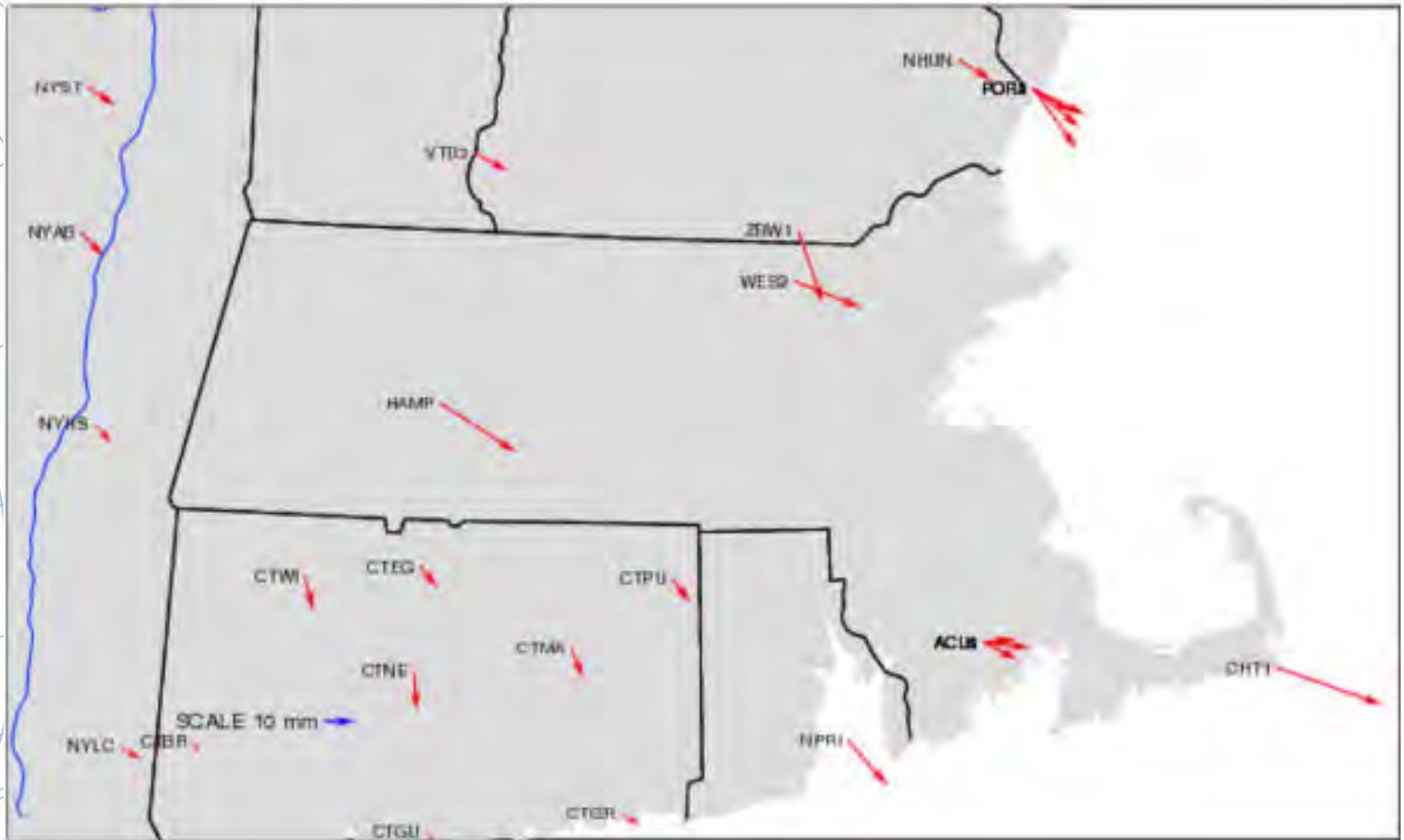
Transformed from IGS08 velocity in Aug 2011.

VX =	0.0017 m/yr	northward	=	-0.0011 m/yr
VY =	0.0006 m/yr	eastward	=	0.0018 m/yr
VZ =	-0.0015 m/yr	upward	=	-0.0010 m/yr

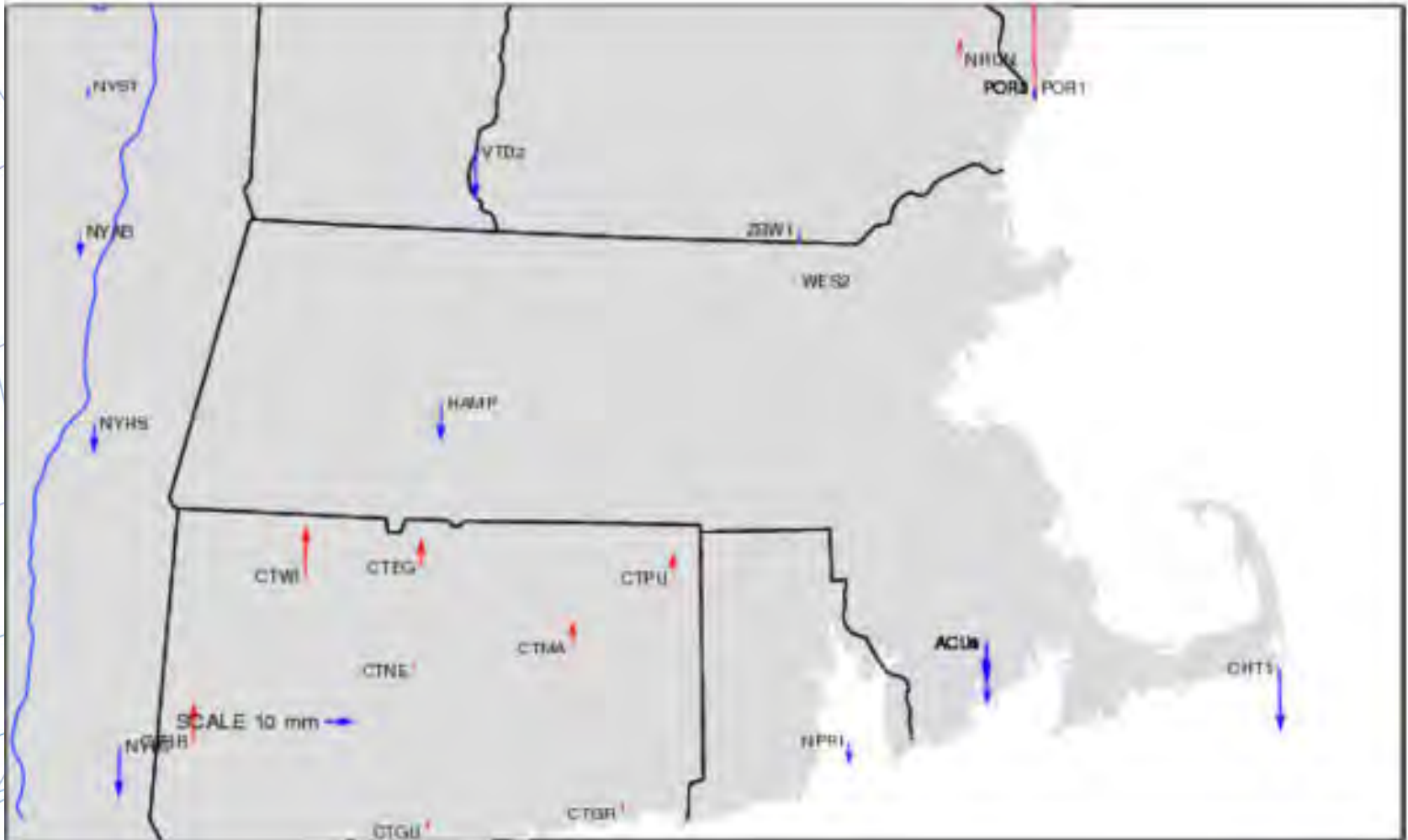
IGS08 - NAD 83(2011)

 $\Delta$ Horiz = 1.047 m $\Delta$ Eht = 1.146 m

MA Horizontal POSITIONS NAD 83(2011) 2010.00 minus NAD 83(CORS96) 2002.00



MA Vertical POSITIONS NAD 83(2011) 2010.00 minus NAD 83(CORS96) 2002.00



# Ten-Year Milestones (2018)

- 1) NGS will compute a pole-to-equator, Alaska-to-Newfoundland geoid model, preferably in conjunction with Mexico and Canada as well as other interested governments, with an accuracy of 1 cm in as many locations as possible
- 2) NGS redefines the vertical datum based on GNSS and a gravimetric geoid
- 3) NGS redefines the national horizontal datum to remove disagreements with the ITRF

# Predicted Positional Changes in 2022 Vicinity of Hyannis, MA.

(Computed for station W 56, pid AB7938)

**HORIZONTAL = 1.19 m (3.9 ft)**

**ELLIPSOID HEIGHT = - 1.25 m (- 4.1 ft)**

Predicted with **HTDP**

**ORTHOMETRIC HEIGHT = - 0.28 m (- 0.9 ft)**

Predicted with **HTDP** and **USGG2009**

**HTDP**

“Coping with Tectonic Motion”

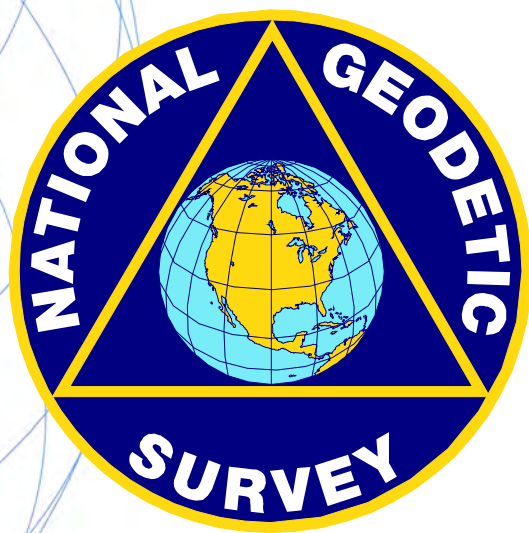
R. Snay & C. Pearson

American Surveyor Magazine, December 2010

[www.Ameriserv.com](http://www.Ameriserv.com)



# GOOD COORDINATION BEGINS WITH GOOD COORDINATES



***MALSCCE***

**GEOGRAPHY WITHOUT GEODESY IS A FELONY**