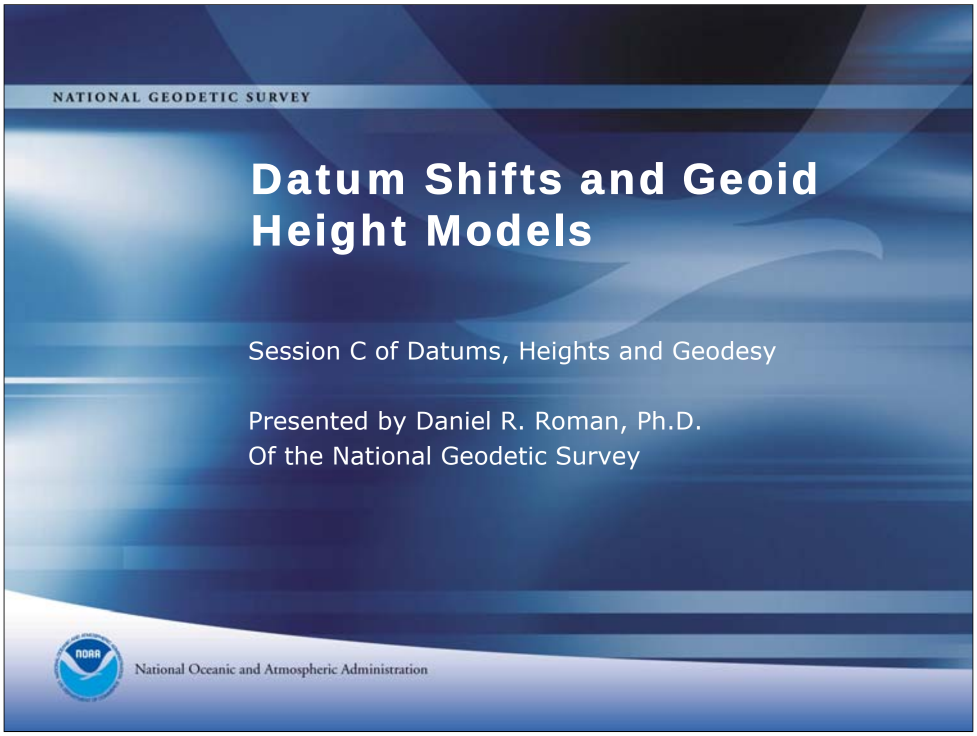
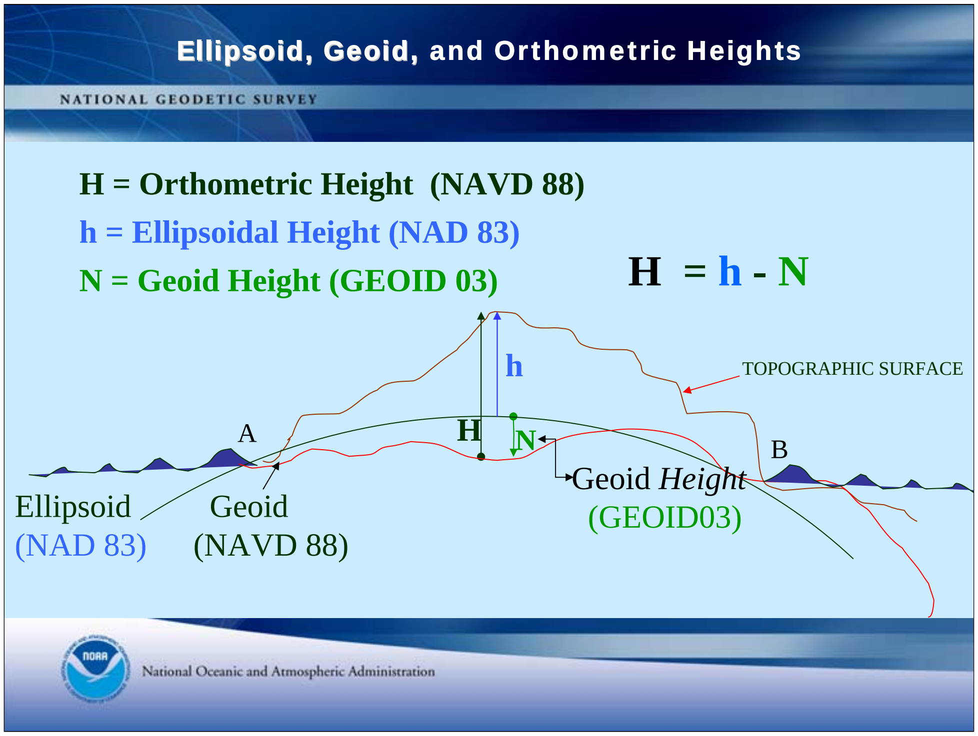


- add in noise element to show how data sigma must be accounted for
- show distribution of GPSBM's - discuss their impact
- show progression of LSC (99, 03, 06)
- discuss performance in extra points in MI
- lastly, discuss data sheets and why not exact fit.



•Mostly surveyors want their heights in NAVD 88 but get them in NAD 83. GEODI03 and other such models provide this transformation. But how is that accomplished? What if you have GPS coordinates in WGS-84 or in some ITRF model? How do you transform to NAD 83? What about if you have heights above NGVD 29 or EGM96? Are heights determined using older geoid height models still valid?

•Transforming between the various datums remains one the commonest requests that I get at NGS. It can also be one of the most complicated to answer. I'll start with the easy one (ellipsoidal transformations) and then move onto the harder one (vertical datums).

Transforming Between Ellipsoid Reference Frames

NATIONAL GEODETIC SURVEY

- Most ellipsoids use the same shell (GRS-80)
- They mainly differ by the location of the center of the reference frame (geocenter)
- The geocenters are re-determined periodically in the International Terrestrial Reference Frame (ITRF)
- Successive ellipsoid datums can be related to earlier models
- Transforming ellipsoids is easy, because they are math constructs (a, f, GM, ω)
- “14-parameter transformation” sounds intimidating, but it’s not: translation along X, Y, & Z (3), rotation around X, Y & Z (3) and scaling (1) plus velocities along all 7 of these.
- Horizontal Time Dependent Positioning (HTDP) enables this
- http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml

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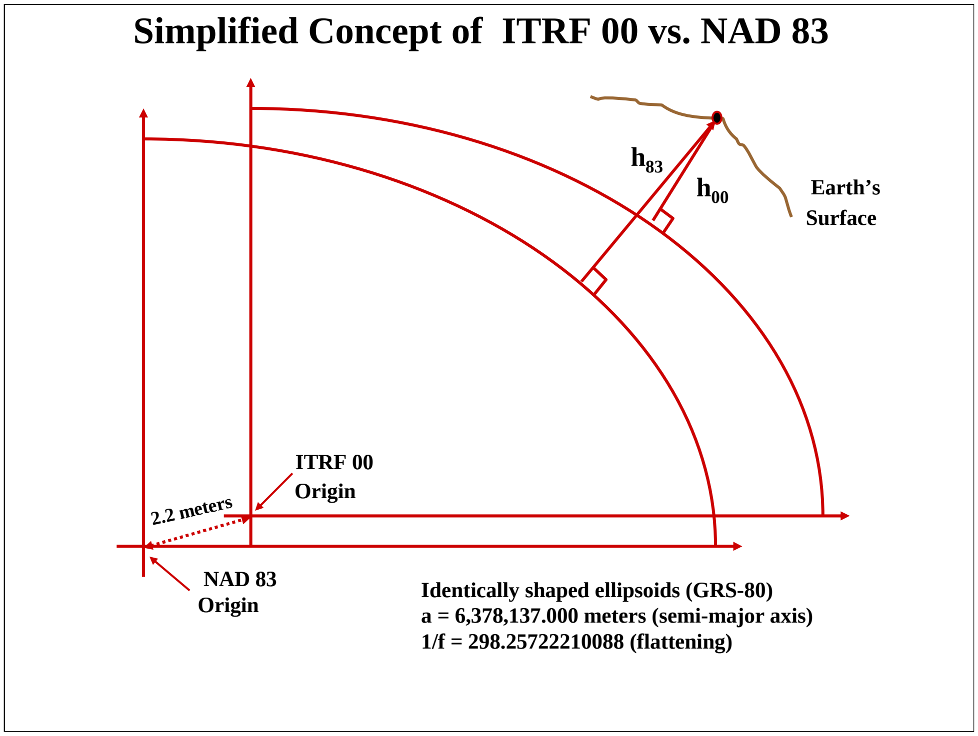
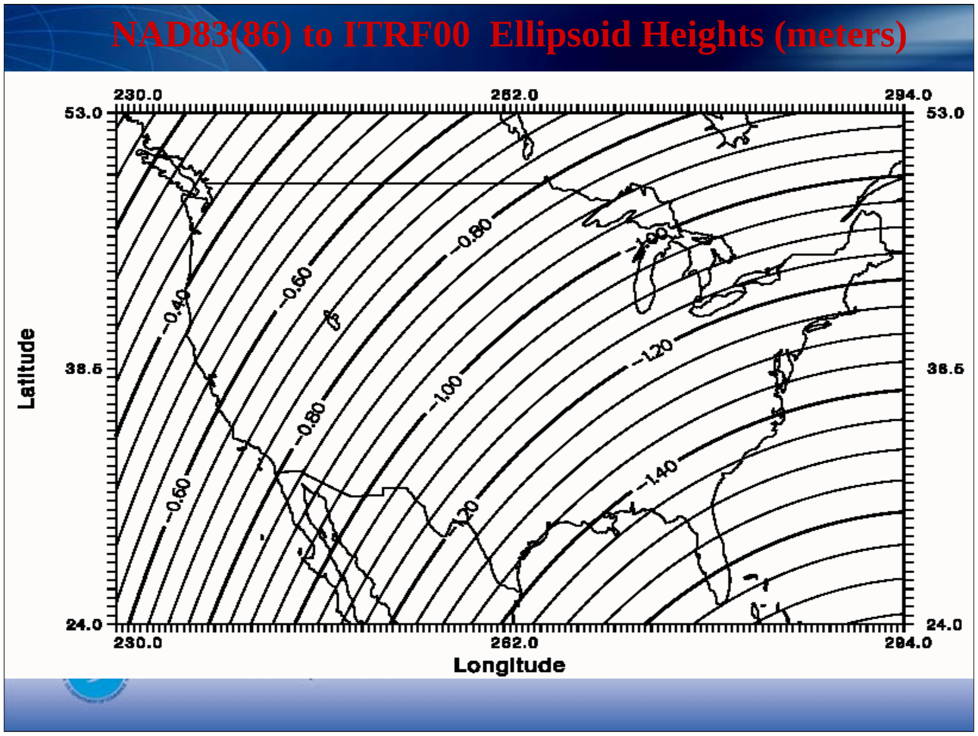


ITRF (International Terrestrial Reference Frame) just has an origin; take NAD83 shaped ellipsoid centered at the ITRF origin to derive ITRF97 ellipsoid heights.

Ellipsoid heights NAD83 vs. ITRF97 - Defined origins are best estimate of the center of mass; NAD83 is not geocentric. Move origin; move ellipsoid surface as illustrated.

Ellipsoid height differences reflect the non-geocentricity of NAD83.

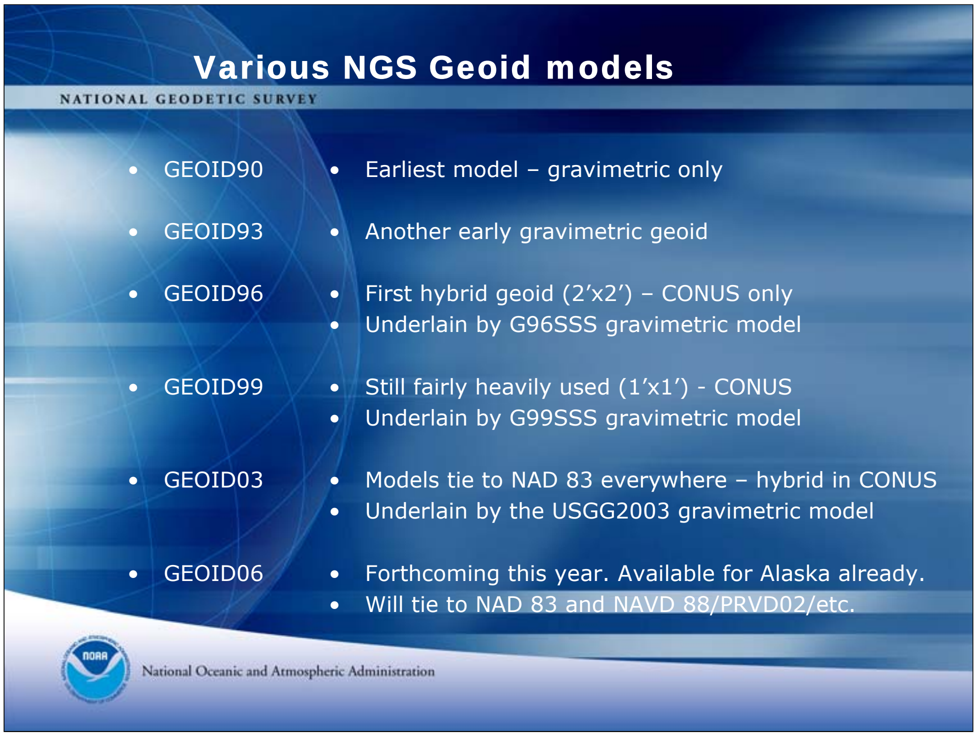


Looking down on offset between ITRF00 and NAD83 ellipsoid heights. Note smooth curved contours as ellipsoidal surfaces move apart.

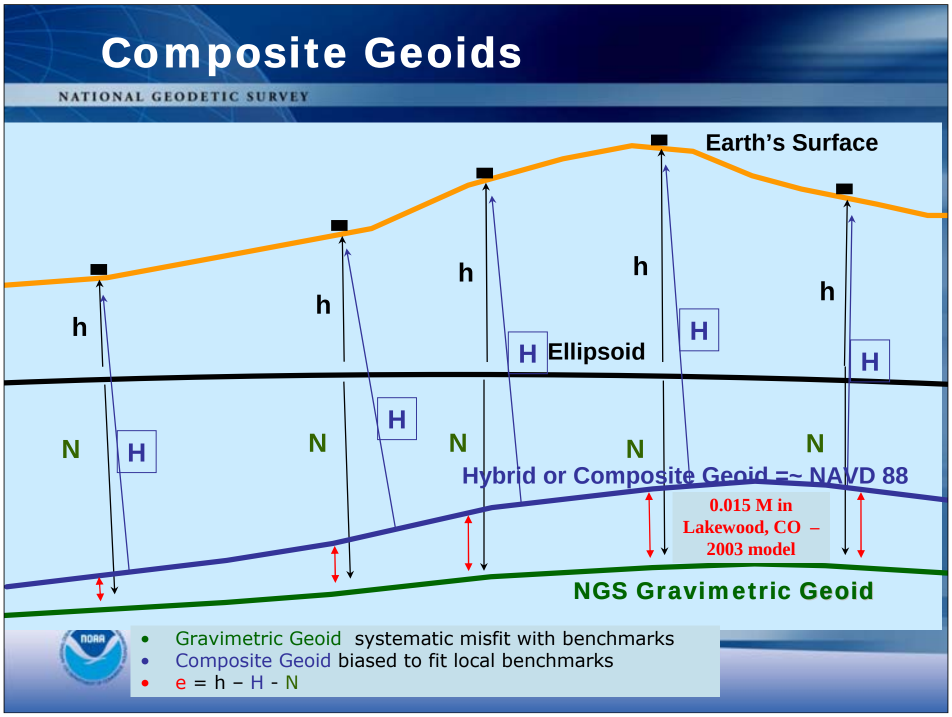
ITRF (International Terrestrial Reference Frame) just has an origin; take NAD83 shaped ellipsoid centered at the ITRF origin to derive ITRF00 ellipsoid heights.

Ellipsoid heights NAD83 vs. ITRF00 - Defined origins are best estimate of the center of mass; NAD83 is not geocentric. Move origin; move ellipsoid surface as indicated by scale shown on map.

Ellipsoid height differences reflect the non-geocentricity of NAD83.



Which model should you use? Usually, the most recent. They are better tied to NAD 83 and NAVD 88 and will provide geoid heights consistent with bench marks in the NGS database.



•to transform from the NGS gravimetric geoid to NAVD 88 is more complicated

•Gravimetric geoid is from derived from gravity measurements

•NAVD 88 bench marks are adjusted using a sea level height at Point au Pere

•There is going to be a slight difference between the 2. If we want to use geoid to compute NAVD 88 heights, it must be consistent with the NAVD 88

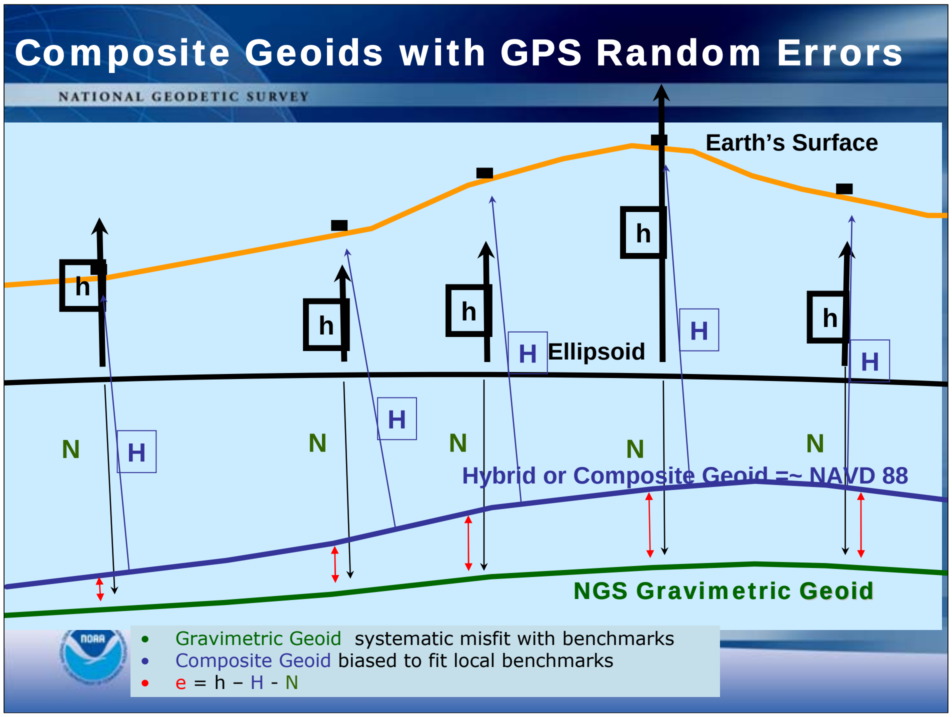
-Therefore we "bias" the geoid to be consistent with the NAVD 88 using high accuracy GPS on NAVD 88 bench marks.

-Use Least Squares Collocation to determine the systematic components while allowing for random GPS observation errors (2-5 cm standard).

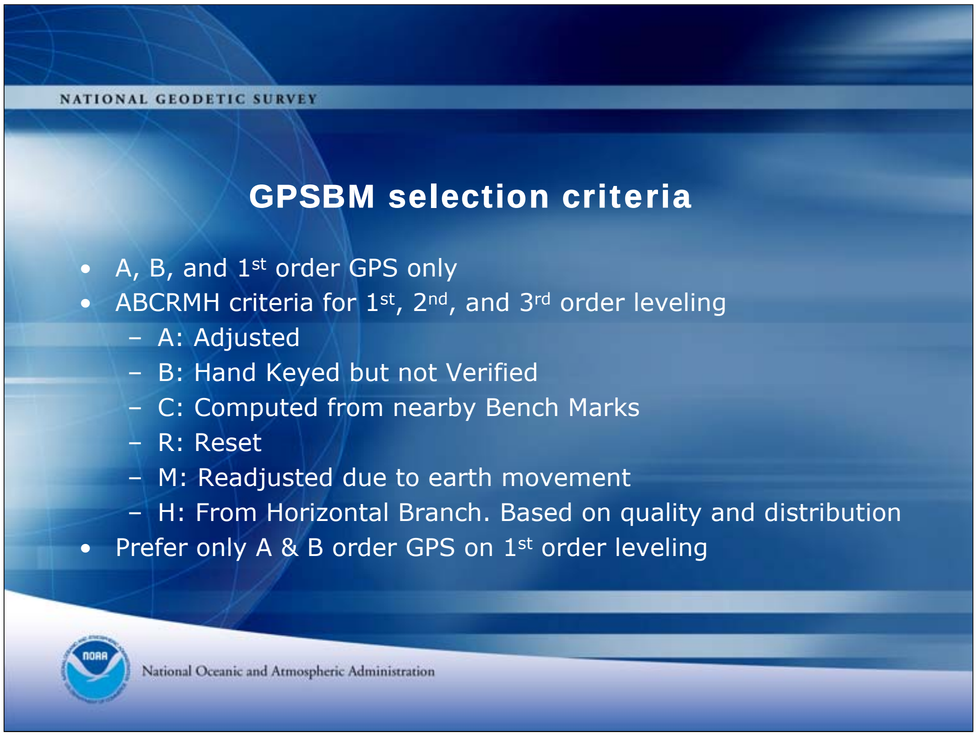
--Use the control points (GPSBM's) to define a surface that can be interpolated to make internally consistent predictions (precision versus accuracy).

-As you can easily see, the quality and distribution of the control, data will directly impact the quality of the predictions.

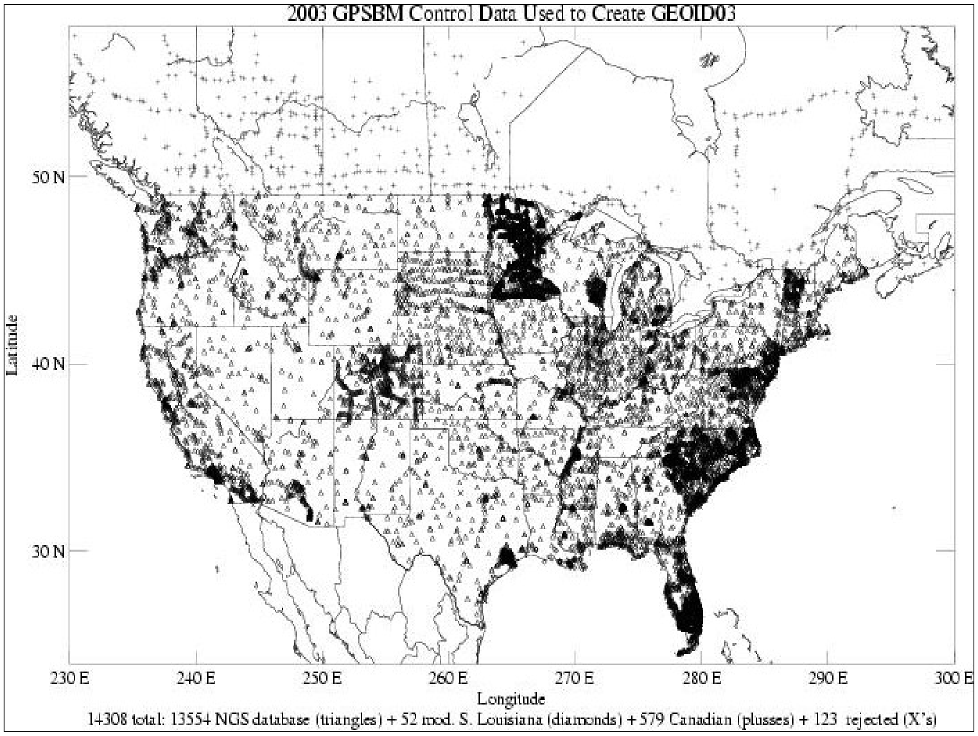
-also note that the error vector residual (e) is a function of **all** the errors sources: from the GPS observations (usually random, but each HARN could have systematic errors), the gravimetric geoid height model (errors in gravity & terrain data as well as theoretical/processing errors can contribute here) as well as any errors in the NAVD 88 network.



- When you allow for random GPS errors, you no longer will get an exact match at GPSBM locations.
- GPS observations include 2-5 cm of random error.
- Hence, h = H + N will not work exactly when you check the data sheets.
- This will be covered later. First a the development of the hybrid geoid will be covered more fully.
- Obviously, selection of the GPSBM's is crucial to developing a good composite geoid height model.



Bench mark heights were not used if they were posted, determined by a single spur, an unvalidated single spur, or from the horizontal branch but from another agency.



-These are the control data used to make GEOID03 (GPS on bench marks: GPSBM's).

-Note the inequitable distribution.

-You could practically grid the GPSBM's in South Carolina and get a good result.

-Other places are not so fortunate…

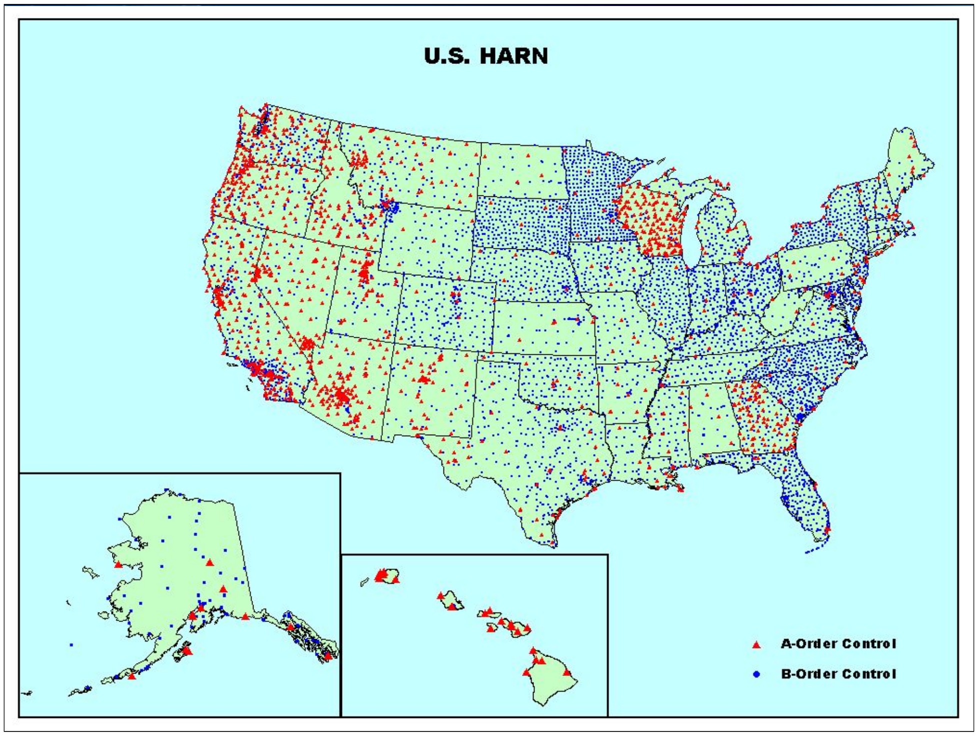
-Also note that this shows distribution but not quality of the points.

-Some regions (e.g., Texas) have systematic problems that impact the GPSBM's and the derived hybrid geoids.

-Current techniques rely on creating models of the systematic effects at multiple wavelengths. If the spatial density doesn't support the shorter wavelength models, then the quality of predictions will commensurately be reduced.

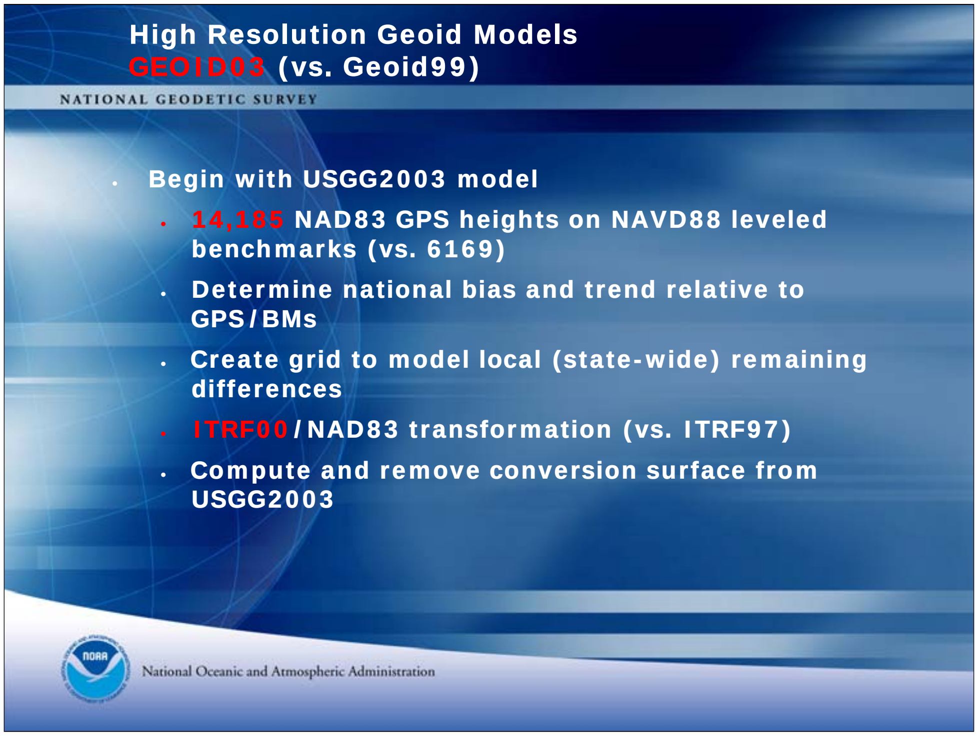
CO: # PTS = 514   Average = 0.0 cm   STD = 3.3 cm

This average is much worse than the national average of 2.4 cm and implies more significant problems exist either in the gravity data, leveling, or GPS observations.



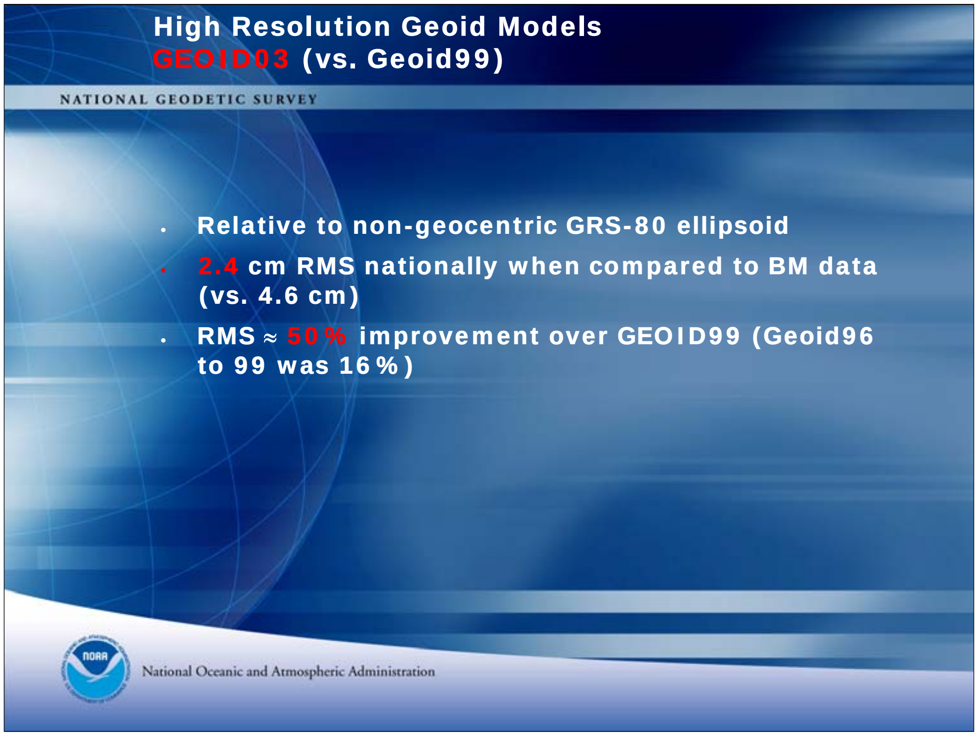
Map of the National A and B Order, HPGN/HARN monumented station coverage as of 1999.

The distribution of the GPSBM's used to make the composite geoid height model is tied closely to this.



GEOID03 - best model for North America; not a true interpretation of the geoid but includes bias to establish best orthometric heights relative to NAVD88.

14,185 GPS/levels bench marks (NAD83/NAVD88); more to be included to further improve future models. GPS/BM constrained to help model reflect NAVD88 orthometric heights then unconstrained for final model.

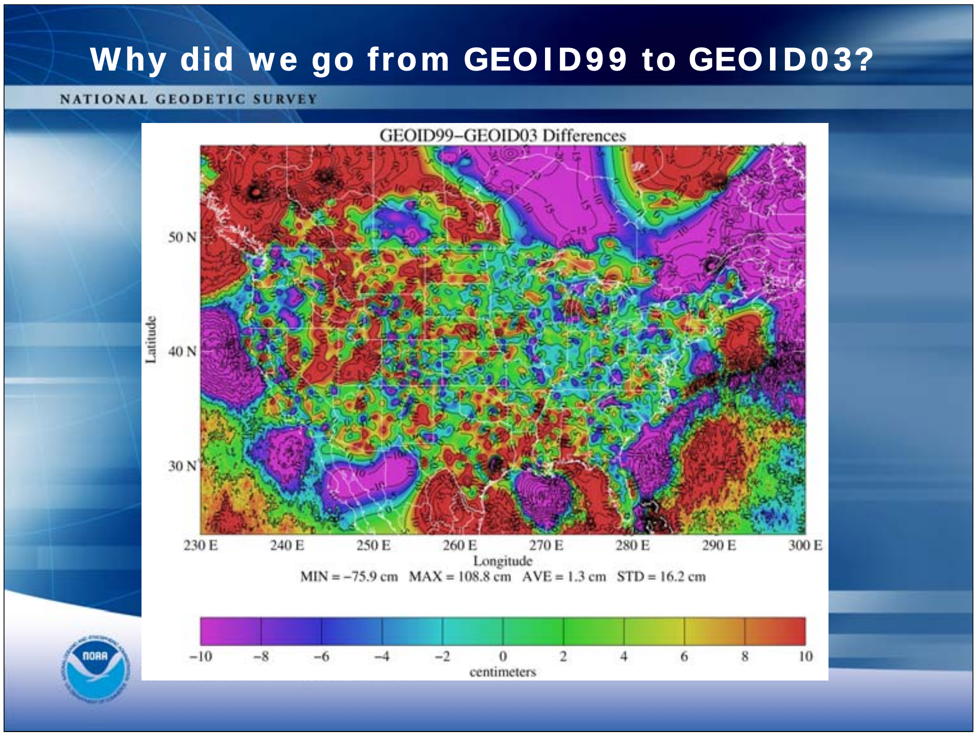


-NAD83 non-COM - model warped to reflect NAD83 (86) non-COM origin.

-2.4 cm RMS when comparing to bench mark data – includes 2 cm random error in GPS observations.

-The improvement largely resulted from the improved technique (multi-matrix), which is why we created it.

-Future models will adopt a similar modeling approach.



One of the chief complaints about GEOID03 was that derived heights were significantly different from GEOID99

What caused this? Why is GEOID03 better?

More Fun with Formulas! Least Squares Collocation

$$\hat{s} = C_{sl}\left(C_{ll} + D_n\right)^{-1} l$$

where: $\hat{s}$ = the solution vector for GPSBM locations and the grid nodes for the output file

C_{sl} = the correlative relationships between all points and the GPSBM residual values

C_{ll} = the correlative relationships between the GPSBM residual values

D_n = the noise matrix for the observed data

l = the observations (GPSBM residual values)

Single Gaussian Function (GEOID99)

$$C_{ll} = A_0 e^{-\left(\frac{D_{ll}}{\kappa L}\right)^2}$$

where: C_{ll} = the correlation elements between two points

A_0 = the amplitude at auto-correlation

D_{ll} = the distance between two points

L = the correlation length (point where $C_{ll} = \frac{1}{2} A_0$)

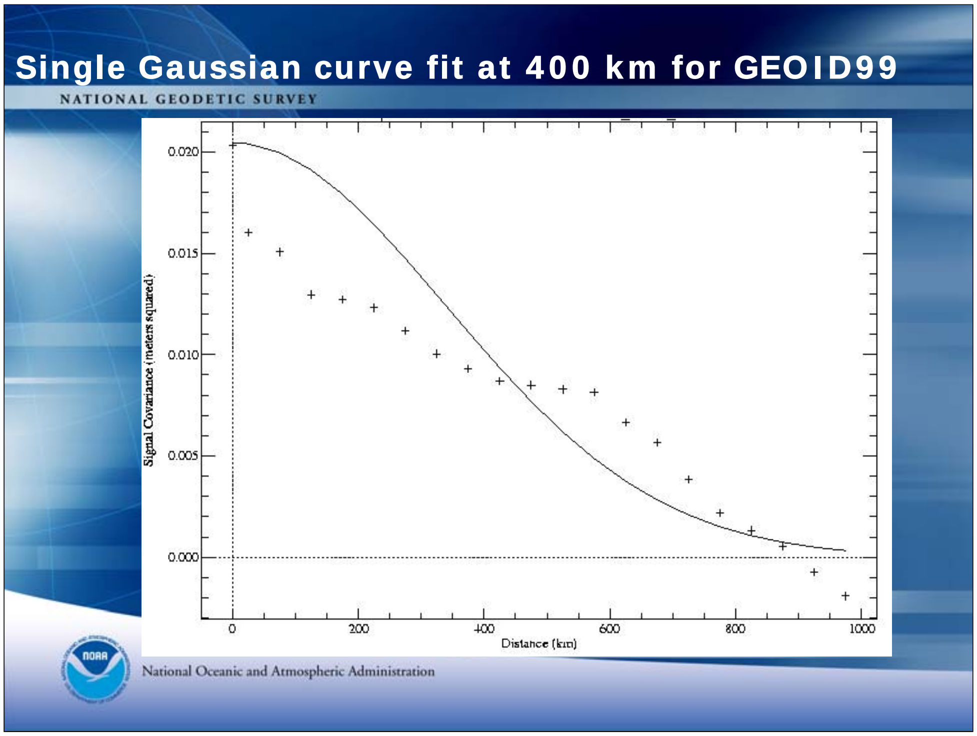
$\kappa = \sqrt{\frac{1}{\ln 2}} \cong 1.2$

Multiple Gaussian Functions (GEOID03)

$$C_{ll} = C_{l_1 l_1} + C_{l_2 l_2}$$

where: $C_{l_1 l_1} = A_0^1 e^{-\left(\frac{D_{ll}}{\kappa L_1}\right)^2}$

$C_{l_2 l_2} = A_0^2 e^{-\left(\frac{D_{ll}}{\kappa L_2}\right)^2}$



While there were fewer points in GEOID99 – the big difference is in how the data were modeled.

A single Gaussian function was fit at 400 km for the half amplitude. Any correlated signal shorter than that is treated as "noise".

GEOID99 Conversion Surface

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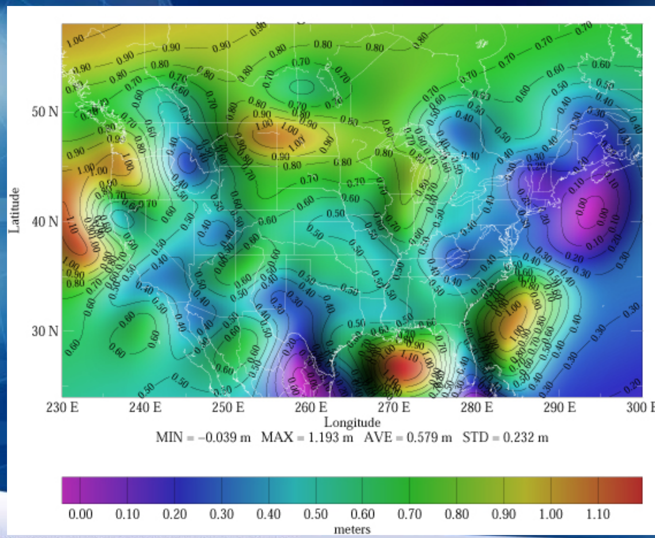

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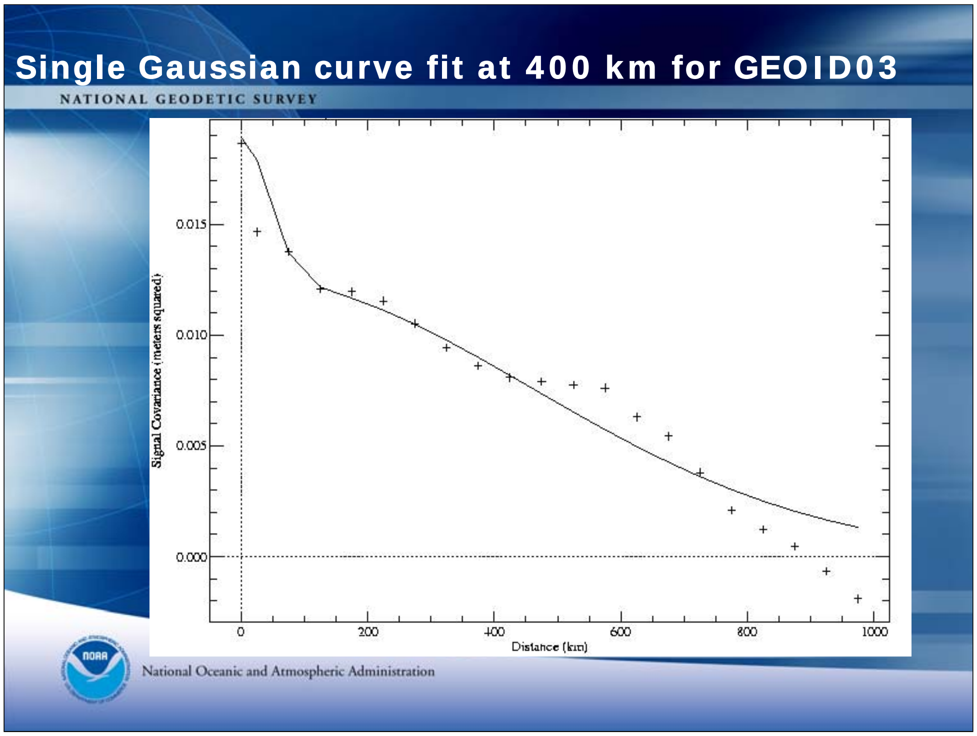

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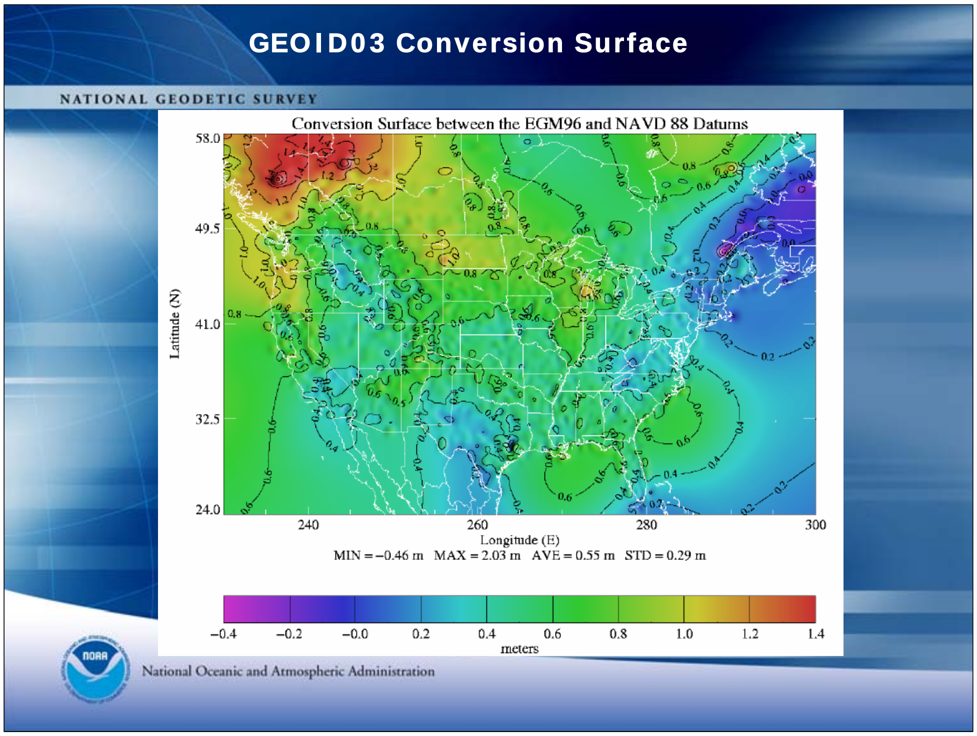
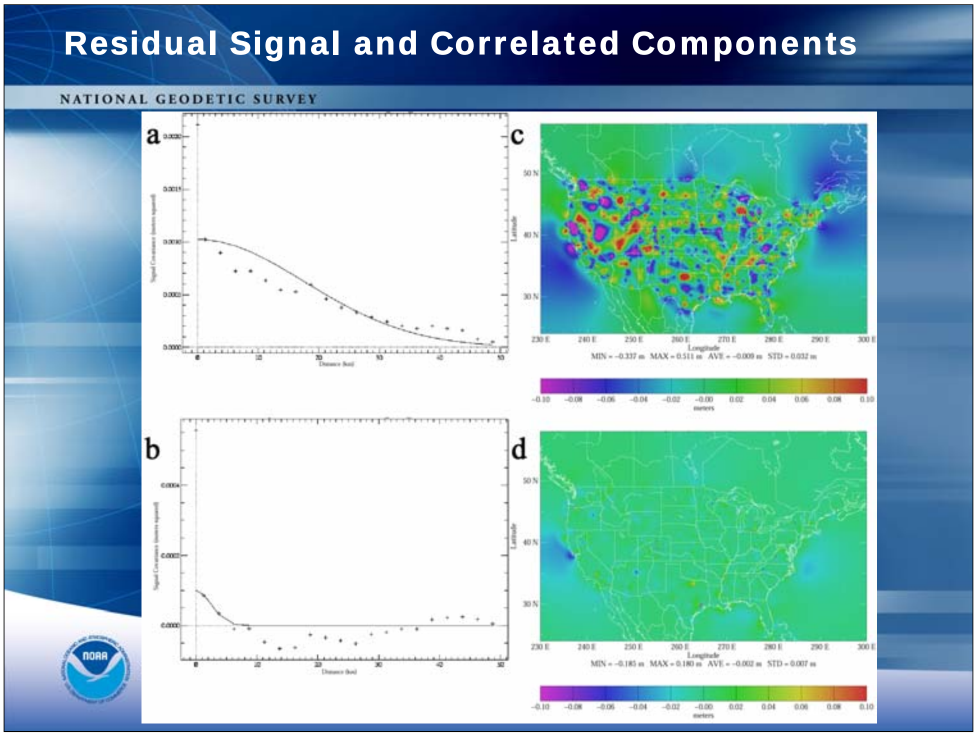


The differences shown here represent the systematic differences



Note that significant signal remains after GEOID99 that has significant spatial extents (county-level and broader)

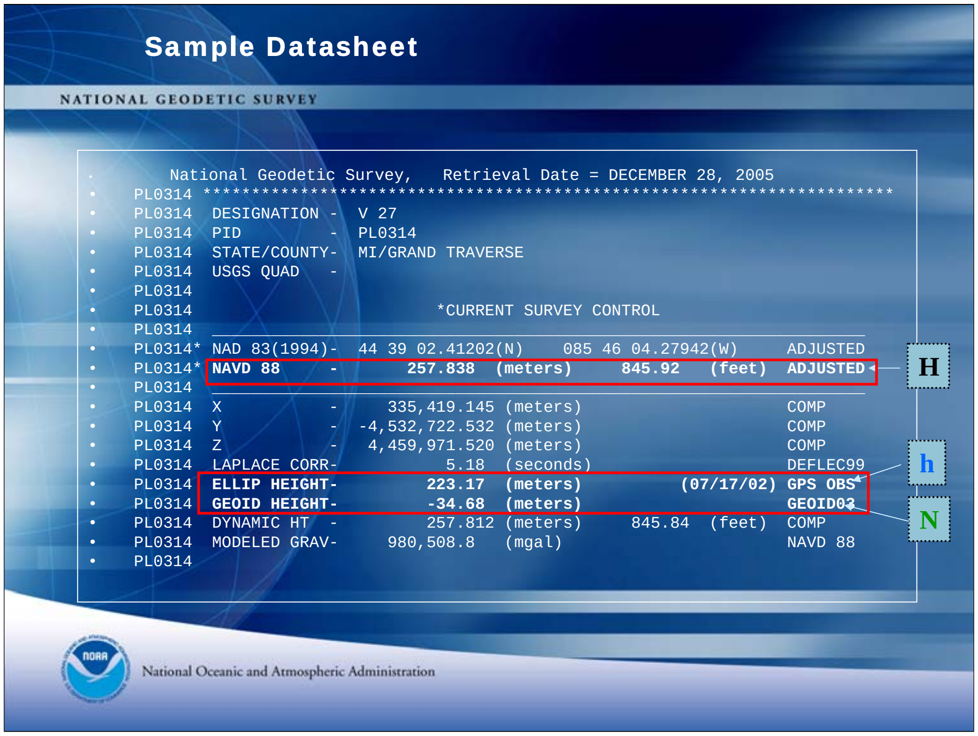
For GEOID03, very little signal remains. Correlated signal falls off at only 5 km. Still have random component, but signals that correlate at about 60-120 km have now been accounted for.

CO & National Statistics for GEOID03

State Code	No. of points	Ave.(cm)	St. Dev.(cm)
CO	514	0.0	3.3
National	14185	0.0	2.4

For more details on the development of GEOID03, see:

Daniel R. Roman, Yan Ming Wang, William Henning, and John Hamilton
Assessment of the New National Geoid Height Model—GEOID03, *Surveying and Land Information Science, Vol. 64, No. 3, 2004, pp. 153-162*



NGS datasheets show all heights where we have them.

Sample Datasheet

NATIONAL GEODETIC SURVEY

```
PL0314
PL0314  HORZ ORDER  -  FIRST
PL0314  VERT ORDER  -  FIRST     CLASS II
PL0314  ELLP ORDER  -  FOURTH    CLASS I
PL0314
PL0314.The horizontal coordinates were established by GPS observations
PL0314.and adjusted by the National Geodetic Survey in February 1997.
PL0314
PL0314.The orthometric height was determined by differential leveling
PL0314.and adjusted by the National Geodetic Survey in June 1991.
PL0314
PL0314.The X, Y, and Z were computed from the position and the ellipsoidal ht.
PL0314
PL0314.The Laplace correction was computed from DEFLEC99 derived deflections.
PL0314
PL0314.The ellipsoidal height was determined by GPS observations
PL0314.and is referenced to NAD 83.
PL0314
PL0314.The geoid height was determined by GEOID03.
PL0314
PL0314.The dynamic height is computed by dividing the NAVD 88
PL0314.geopotential number by the normal gravity value computed on the
PL0314.Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45
PL0314.degrees latitude (g = 980.6199 gals.).
PL0314
PL0314.The modeled gravity was interpolated from observed gravity values.
PL0314
```

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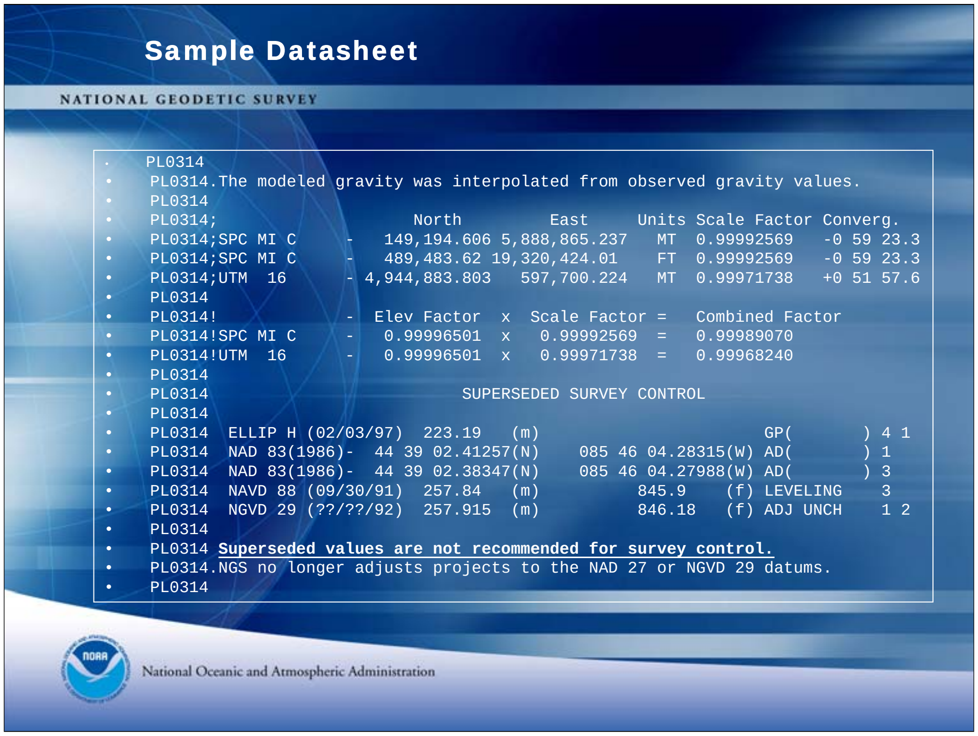
The source for each height is explained below the coordinates



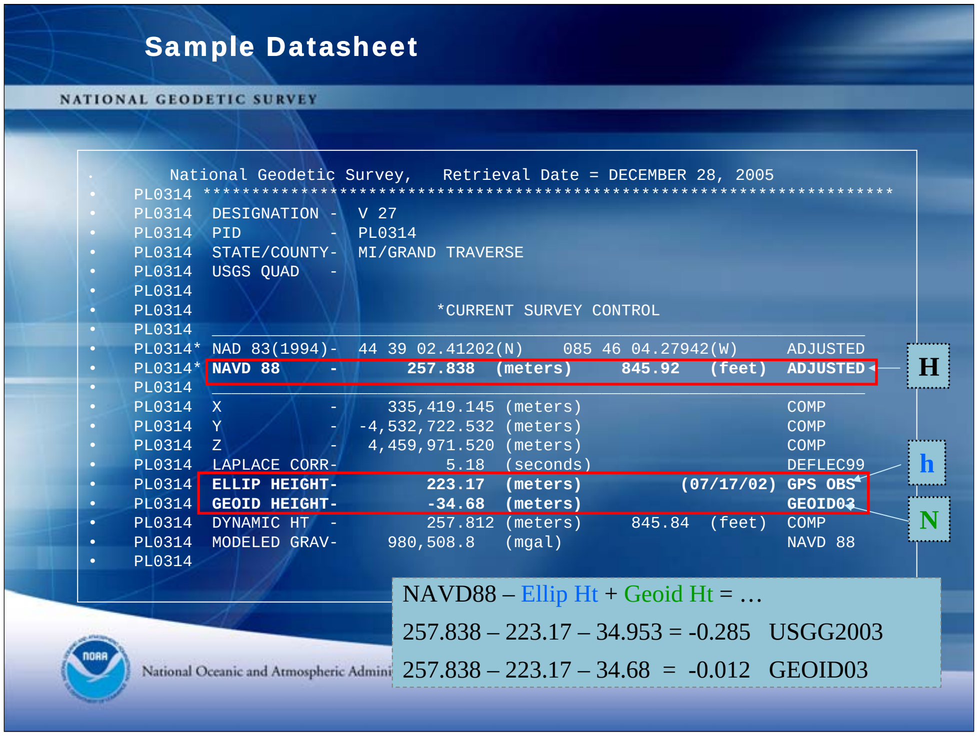
-Modeled gravity comes from the NAVD 88 gravity interpolation program NOT the Surface Gravity Interpolation tool

-The Surface tool draws from the existing database, while NAVD 88 tool draws from a database made static at the time of the national adjustment (1991) to make sure values are consistent.

-impact can be decimeter in high altitudes.

Sample Datasheet

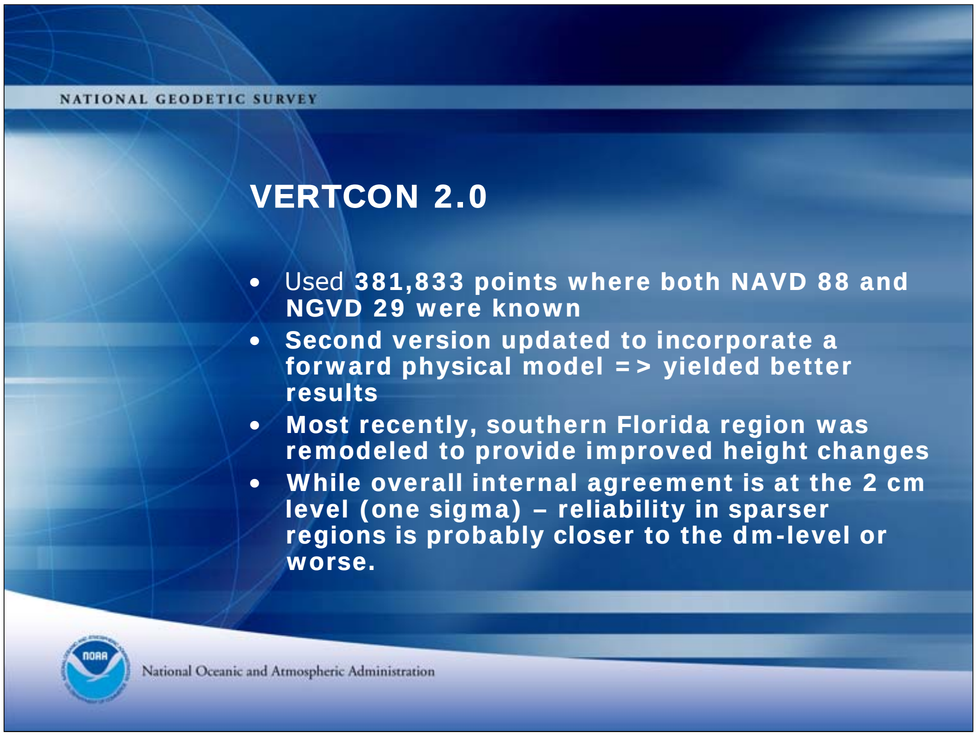

```
PL0314_U.S. NATIONAL GRID SPATIAL ADDRESS: 16TEQ9770044884(NAD 83)
PL0314_MARKER: DB = BENCH MARK DISK
PL0314_SETTING: 7 = SET IN TOP OF CONCRETE MONUMENT
PL0314_SP_SET: CONCRETE POST
PL0314_STAMPING: V 27 1930 846.176
PL0314_MARK LOGO: CGS
PL0314_MAGNETIC: N = NO MAGNETIC MATERIAL
PL0314_STABILITY: B = PROBABLY HOLD POSITION/ELEVATION WELL
PL0314_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
PL0314+SATELLITE: SATELLITE OBSERVATIONS - October 24, 1992
PL0314
PL0314  HISTORY     - Date     Condition        Report By
PL0314  HISTORY     - 1930     MONUMENTED       CGS
PL0314  HISTORY     - 1951     GOOD             NGS
PL0314  HISTORY     - 1984     GOOD             NGS
PL0314  HISTORY     - 19890428 GOOD             NGS
PL0314  HISTORY     - 1990     GOOD             USPSQD
PL0314  HISTORY     - 19910701 GOOD             NGS
PL0314  HISTORY     - 19920824 GOOD             MIDT
PL0314  HISTORY     - 19921024 GOOD             MIDT
PL0314  HISTORY     - 19971029 GOOD             USPSQD
PL0314
PL0314                          STATION DESCRIPTION
PL0314
PL0314'DESCRIBED BY NATIONAL GEODETIC SURVEY 1951
PL0314'IN INTERLOCHEN.
PL0314'AT INTERLOCHEN, 131 FEET EAST OF THE JUNCTION OF THE ABANDONED
PL0314'BRANCH OF THE MANISTEE AND NORTHEASTERN RAILROAD AND THE C AND
```



-In a perfect world these heights would add up mathematically. But every height is derived in a way that includes some measure of error, whether it is from an observation and adjustment process or simply because it is derived from a model. The purpose of creating a version of the geoid model that is biased to fit the NAVD88 is to provide a means to compute that NAVD88 height from GPS and the model alone. You can see here how the change from the scientific model to the hybrid model provides a better fit between the 3 heights. And as the geoid model improves, along with our ability to measure and compute better ellipsoid heights, these differences will get smaller and smaller.

Other Types of Transformations

- VERTCON: NGVD 29 to NAVD 88
- NADCON: NAD 27 to NAD 83
- VDATUM: Transforms between all surfaces using a lot of the tools and models you've seen here


NATIONAL GEODETIC SURVEY
VERTCON 2.0
• Used 381,833 points where both NAVD 88 and NGVD 29 were known
• Second version updated to incorporate a forward physical model => yielded better results
• Most recently, southern Florida region was remodeled to provide improved height changes
• While overall internal agreement is at the 2 cm level (one sigma) – reliability in sparser regions is probably closer to the dm-level or worse.
National Oceanic and Atmospheric Administration

Height Differences Between NAVD 88 and NGVD 29

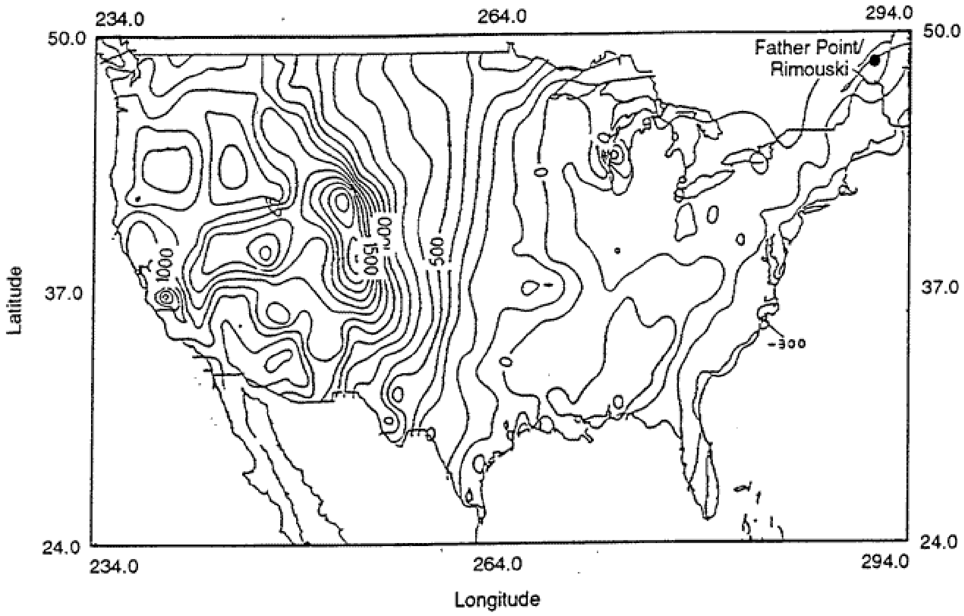
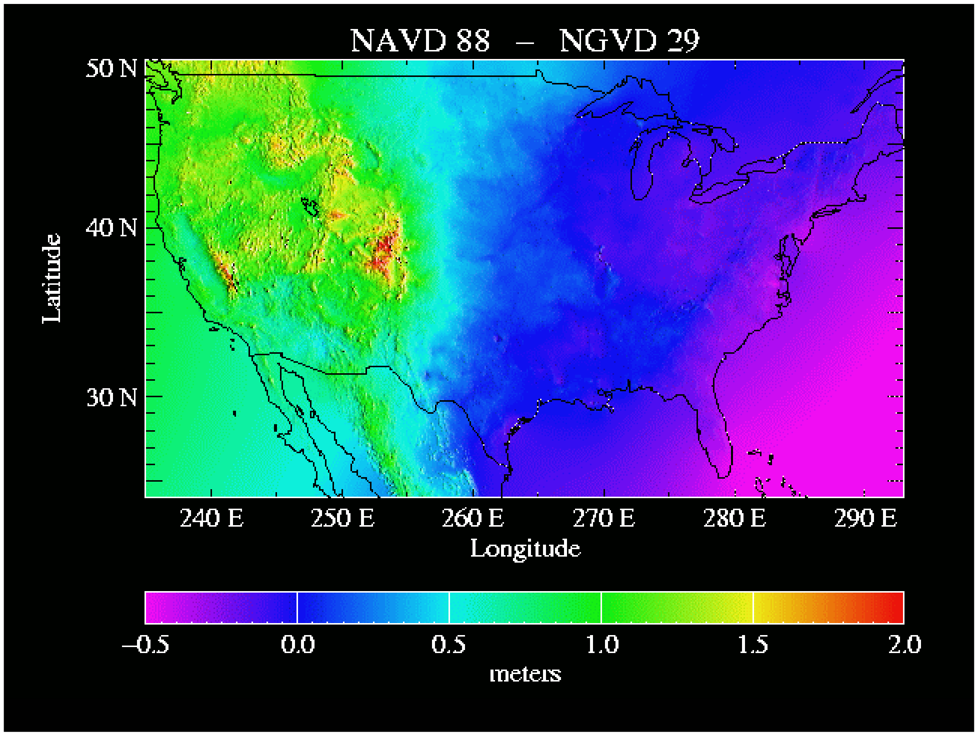


Figure 4. Contour map depicting height differences between NAVD 88 and NGVD 29 (units = mm).

Area contour map - note areas of extreme and moderate changes between datums.

If you check in to NGVD29 and not NAVD88 - need to apply orthometric correction to level heights in that area.

LEVEL_DH program provides a means to remove orthometric corrections to level differences between adjacent bench marks. These corrections don't allow direct comparisons between optically derived differences and those published.

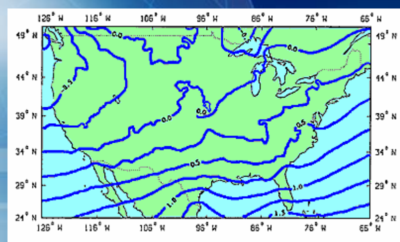


National color map - differences between NGVD29 and NAVD88 datums

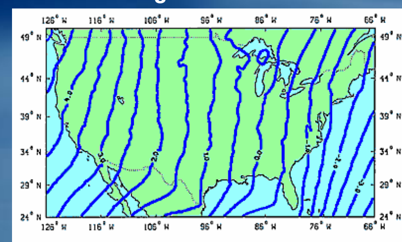
Portrays general east - west tilt; rugged areas indicate major changes whereas smooth are minor changes. 2 & 3 cm level differences over steep gradients.

NADCON

Latitude



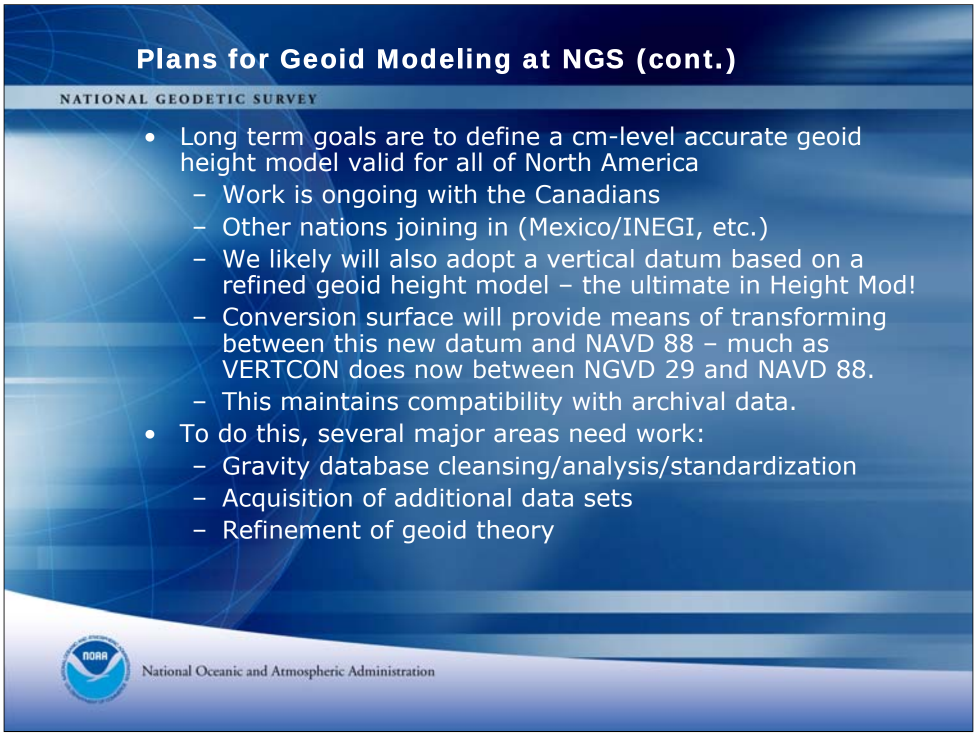
Longitude



- Used more than 150,000 horizontal control points
- The accuracy of transformations between NAD 27 and NAD 83 (1986) are typically 12-18 cm and 5-6 cm between NAD 83 (1986) and HPGN.
- NADCON is the Federal standard for NAD 27 to NAD 83 datum transformations.

Plans for Geoid Modeling at NGS

- Near term plans are to define gravimetric geoids and hybrid geoids for all U.S. territories (USGG2006 & GEOID06).
- Gravimetric geoids would all have a common Wo value (geoid datum) and be based on GRACE-based global gravity models such as the forthcoming EGM07 from NGA
- Gravimetric geoids will be tested against tide gauges and lidar-observed sea surface heights to confirm choice of Wo.
- Hybrid geoids would be tied to NAD 83 & local vertical datums
  - NAVD 88 for Alaska and CONUS
  - PRVD02 for Puerto Rico
  - Etc.
- The quality of VDatum will be improved as the ties between the oceanic and terrestrial datums are better understood.
- Likewise, it would be very useful in providing decimeter or better *accurate* heights to estimate flooding potential.



-Need seamless gravity data to reduce errors in gravity to geoid modeling

-Need additional gravity outside of U.S. areas – altimetric, neighboring countries

-Also need other data such as density anomalies and terrain data

-Current approach uses many simplifications – a more rigorous approach will reduce errors

-aerogravity fills in gaps and identifies systematic problems in gravity data (shipborne and terrestrial)

QUESTIONS?

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- Jarir Saleh, ERT contractor, gravity database analysis
- William Waickman, programming & database access
- Ajit Sing, Datum Transformation Expert
- Website: http://www.ngs.noaa.gov/GEOID/
- Phone: 301-713-3202