# The NGS Gravity Program and Geoid Modeling

Professional Land Surveyors of Colorado
2006 Fall Technical Program and Annual Meeting

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# OUTLINE OF TALK



- Introduction
- Overview of current gravimetric geoid models
- Overview of current hybrid geoids
- Heights and the datasheet
- Plans for Geoid Modeling at NGS
- Ongoing research areas
- Of local interest
- Conclusions

# GEOIDS versus GEOID *HEIGHTS*

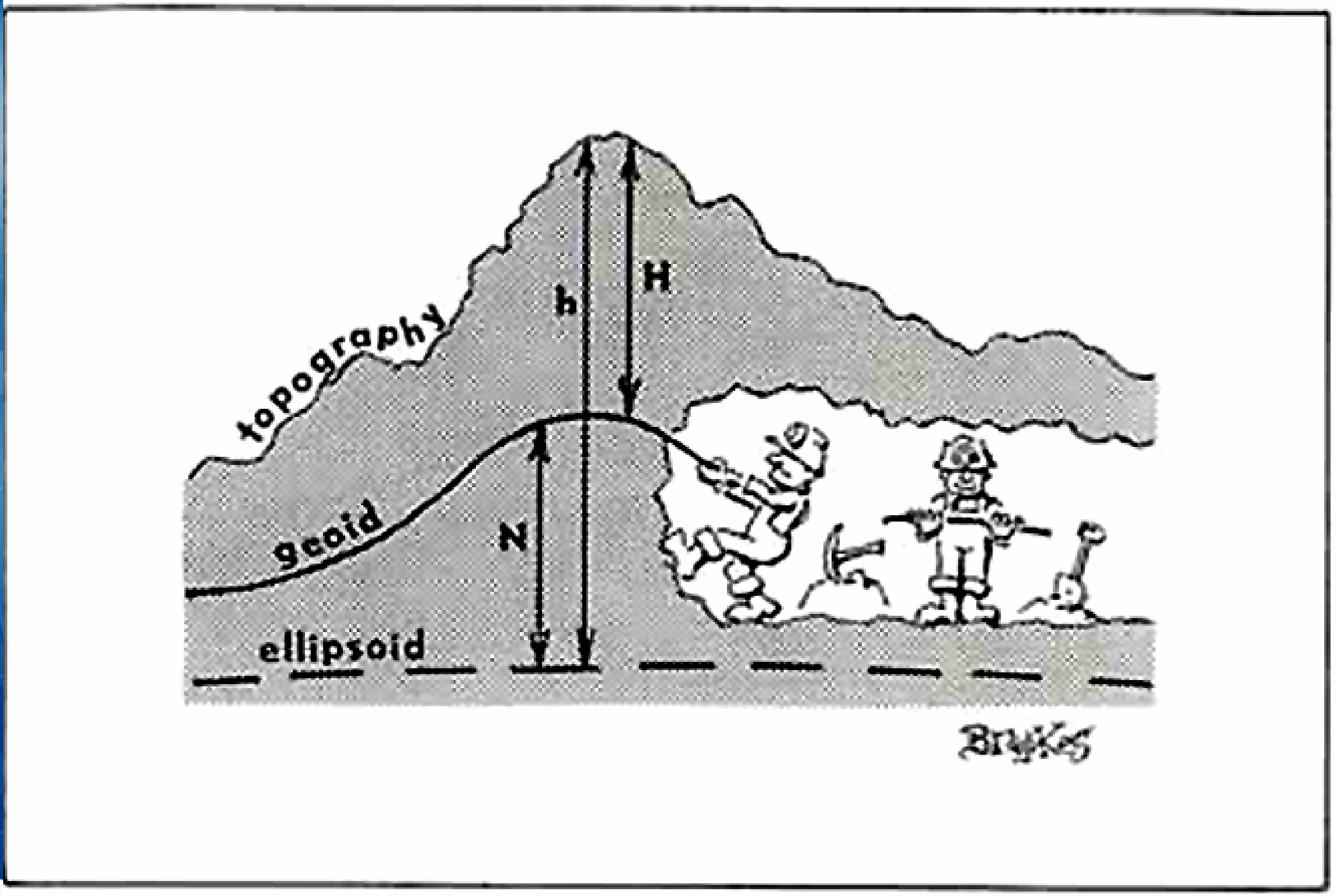


- "The *equipotential surface* of the Earth's gravity field which best fits, in the least squares sense, (global) mean sea level."*
- Can't see the surface or measure it directly.
- Can be modeled from gravity data as they are mathematically related.
- Note that the geoid is a vertical *datum* surface.
- A geoid *height* is the ellipsoidal height from an ellipsoidal datum to a geoid.
- Hence, geoid height models are directly tied to the geoid and ellipsoid that define them (i.e., geoid height models are <u>not</u> interchangeable).

*Definition from the Geodetic Glossary, September 1986

# In Search of the Geoid…






In Search of the Geoid

Courtesy of Natural Resources Canada www.geod.nrcan.gc.ca/index_e/geodesy_e/geoid03_e.html

# High Resolution Geoid Models
## G99SSS (Scientific Model)



- Earth Gravity Model of 1996 (EGM96)
- 2.6 million terrestrial, ship-borne, and altimetric gravity measurements
- 30 arc second Digital Elevation Data
- 3 arc second DEM for the Northwest USA
  - Decimated from 1 arc second NGSDEM99
- Computed on 1 x 1 arc minute grid spacing
- GRS-80 ellipsoid centered at ITRF97 origin

Long Wavelength - global

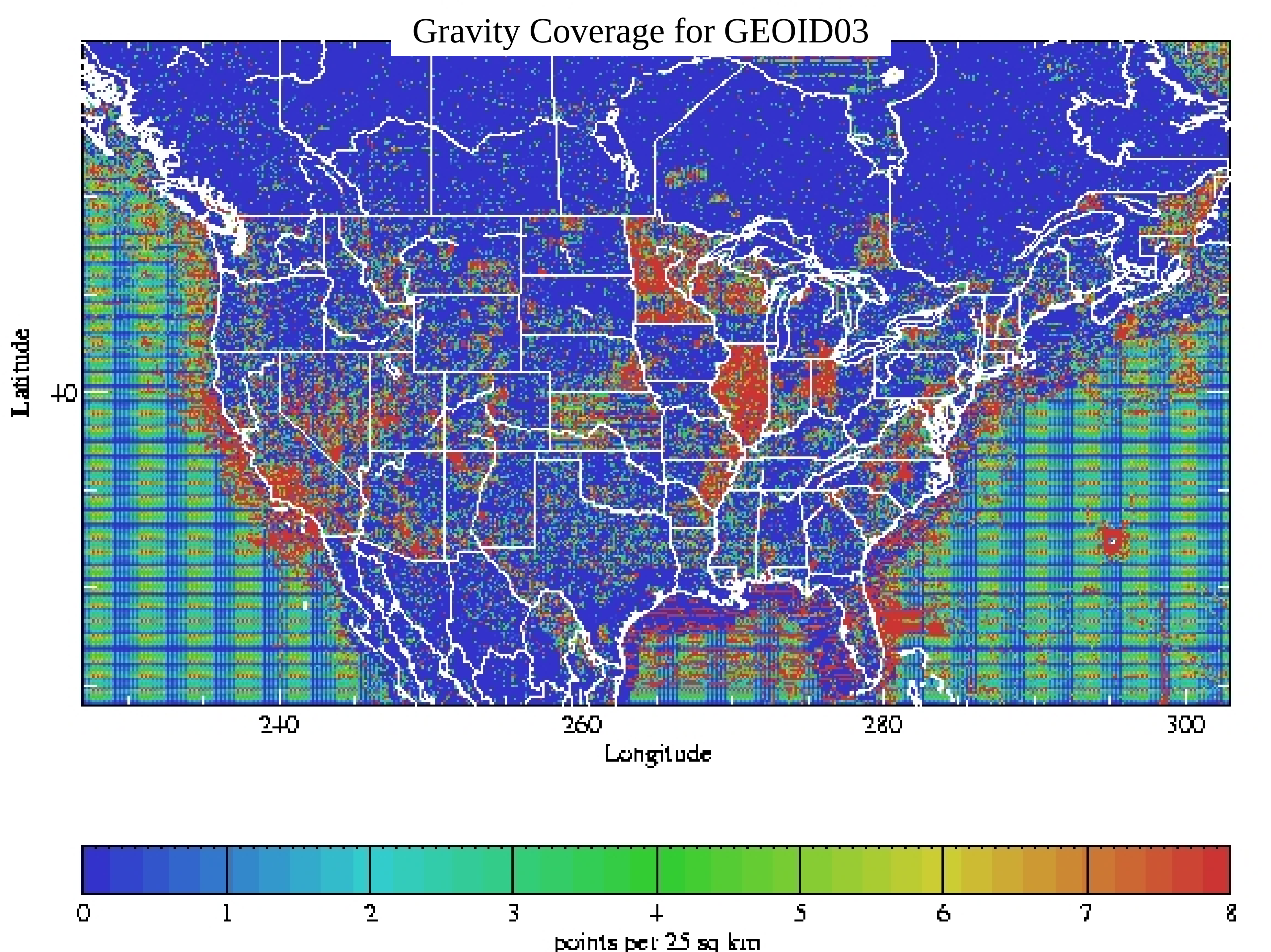
Medium Wavelength - regional

Short Wavelength - local

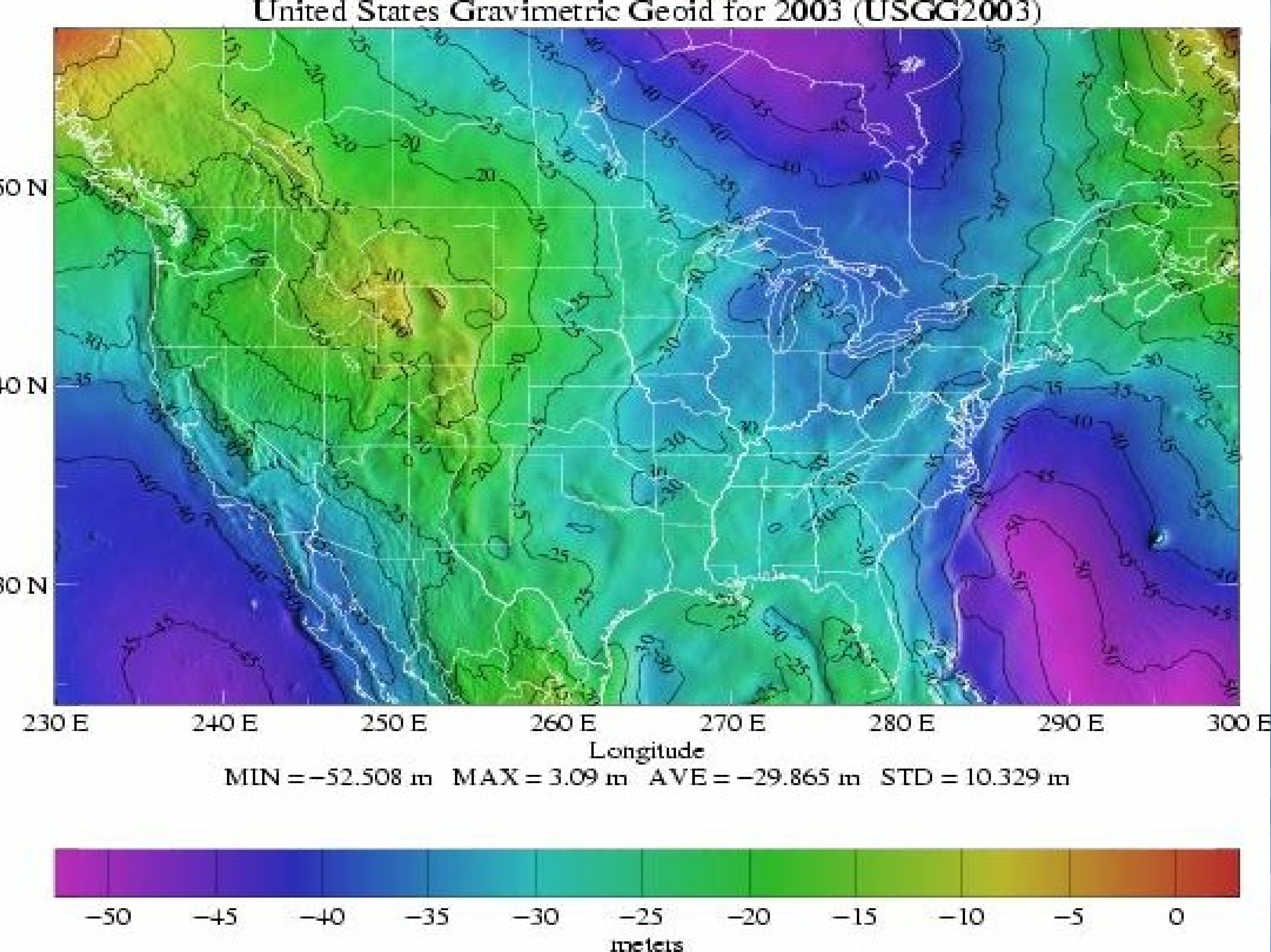
# High Resolution Geoid Models
## USGG2003 (Scientific Model)



- 2.6 million terrestrial, ship, and altimetric gravity measurements
  - offshore altimetry from GSFC.001 instead of KMS98
- 30 arc second Digital Elevation Data
- 3 arc second DEM for the Northwest USA
  - Decimated from 1 arc second NGSDEM99
- Earth Gravity Model of 1996 (EGM96)
- Computed on 1 x 1 arc minute grid spacing
- GRS-80 ellipsoid centered at ITRF00 origin



Gravity Coverage for GEOID03
Latitude
40
240
260
280
300
Longitude
0
1
2
3
4
5
6
7
8
points per 25 sq km


United States Gravimetric Geoid for 2003 (USGG2003)
50 N
40 N
30 N
230 E
240 E
250 E
260 E
270 E
280 E
290 E
300 E
Longitude
MIN = −52.508 m MAX = 3.09 m AVE = −29.865 m STD = 10.329 m
−50
−45
−40
−35
−30
−25
−20
−15
−10
−5
0
meters

# Ellipsoid, Geoid, and Orthometric Heights

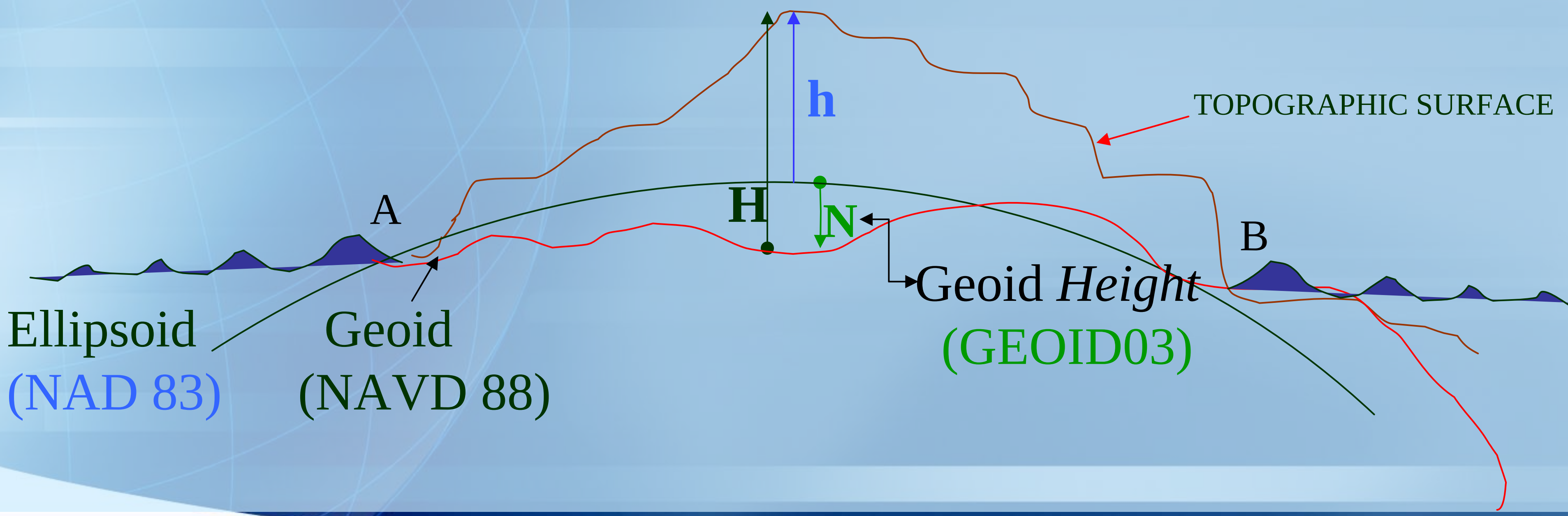


**H = Orthometric Height (NAVD 88)**

**h = Ellipsoidal Height (NAD 83)**

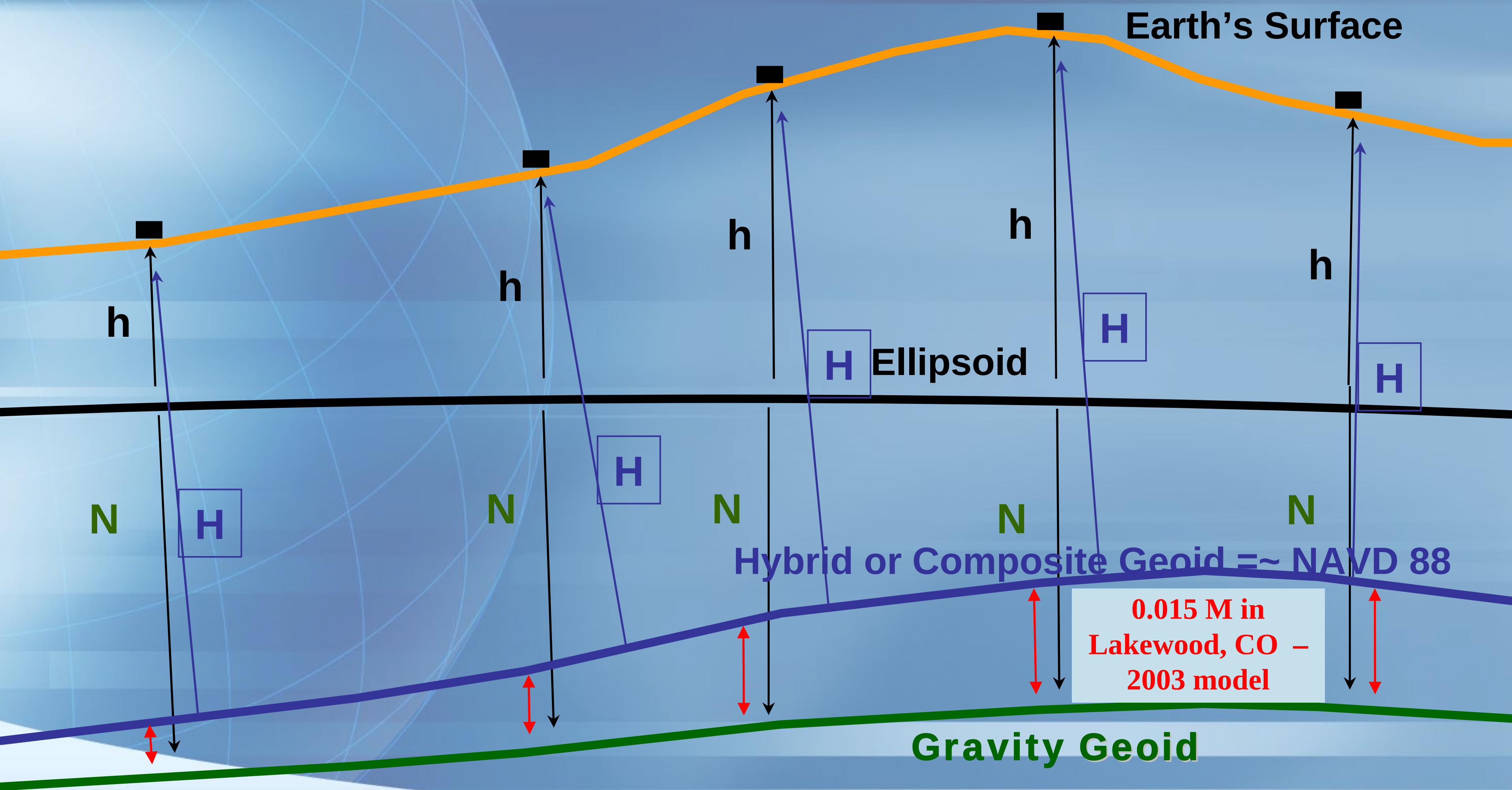
**N = Geoid Height (GEOID 03)**

$$H = h - N$$



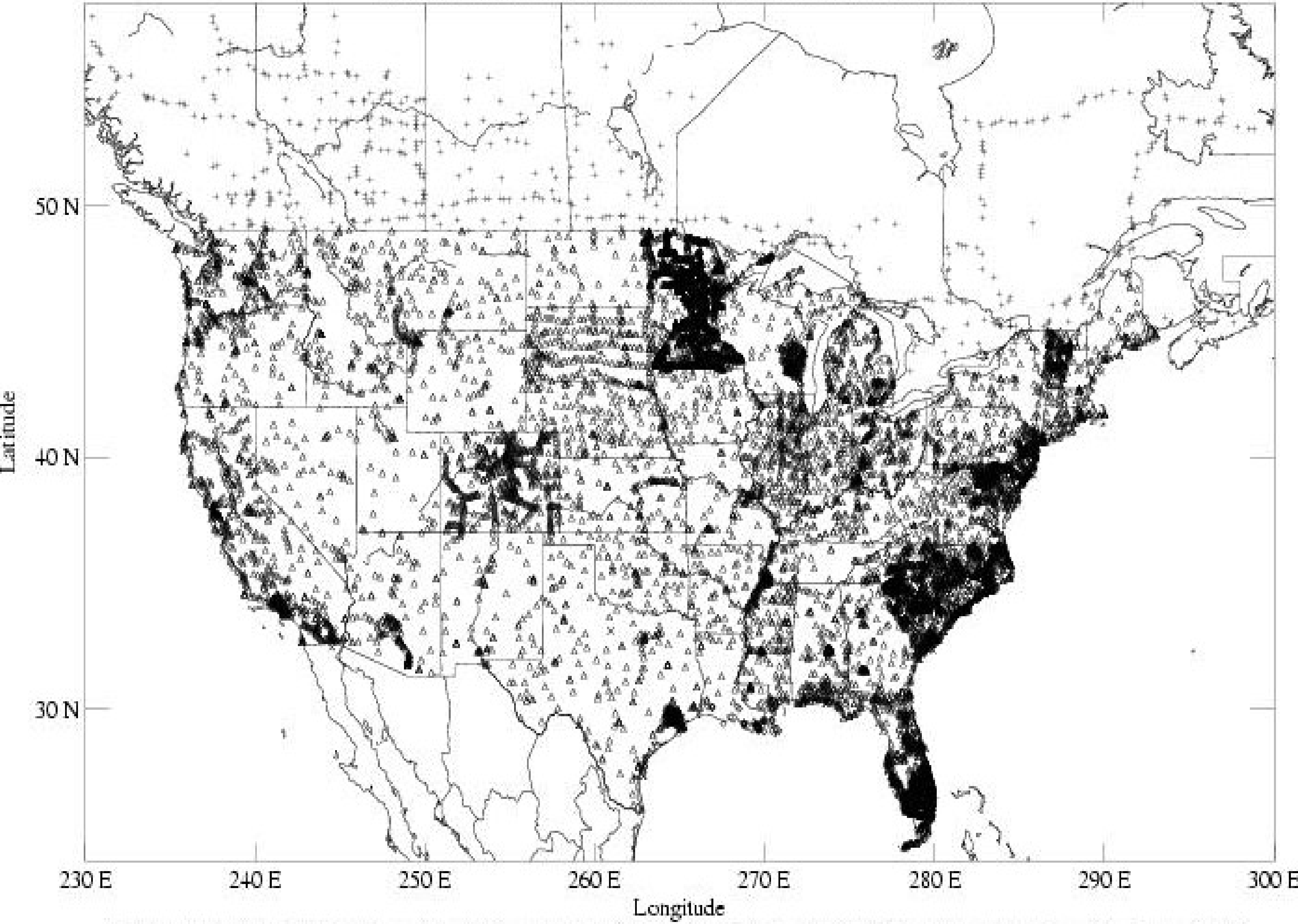
# Composite Geoids

NATIONAL GEODETIC SURVEY




- Gravity Geoid systematic misfit with benchmarks
- Composite Geoid biased to fit local benchmarks
- e = h – H - N

2003 GPSBM Control Data Used to Create GEOID03




14308 total: 13554 NGS database (triangles) + 52 mod. S. Louisiana (diamonds) + 579 Canadian (plusses) + 123 rejected (X's)

# High Resolution Geoid Models
# GEOID03 (vs. Geoid99)



- Begin with USGG2003 model
  - 14,185 NAD83 GPS heights on NAVD88 leveled benchmarks (vs. 6169)
  - Determine national bias and trend relative to GPS/BMs
  - Create grid to model local (state-wide) remaining differences
  - ITRF00/NAD83 transformation (vs. ITRF97)
  - Compute and remove conversion surface from USGG2003

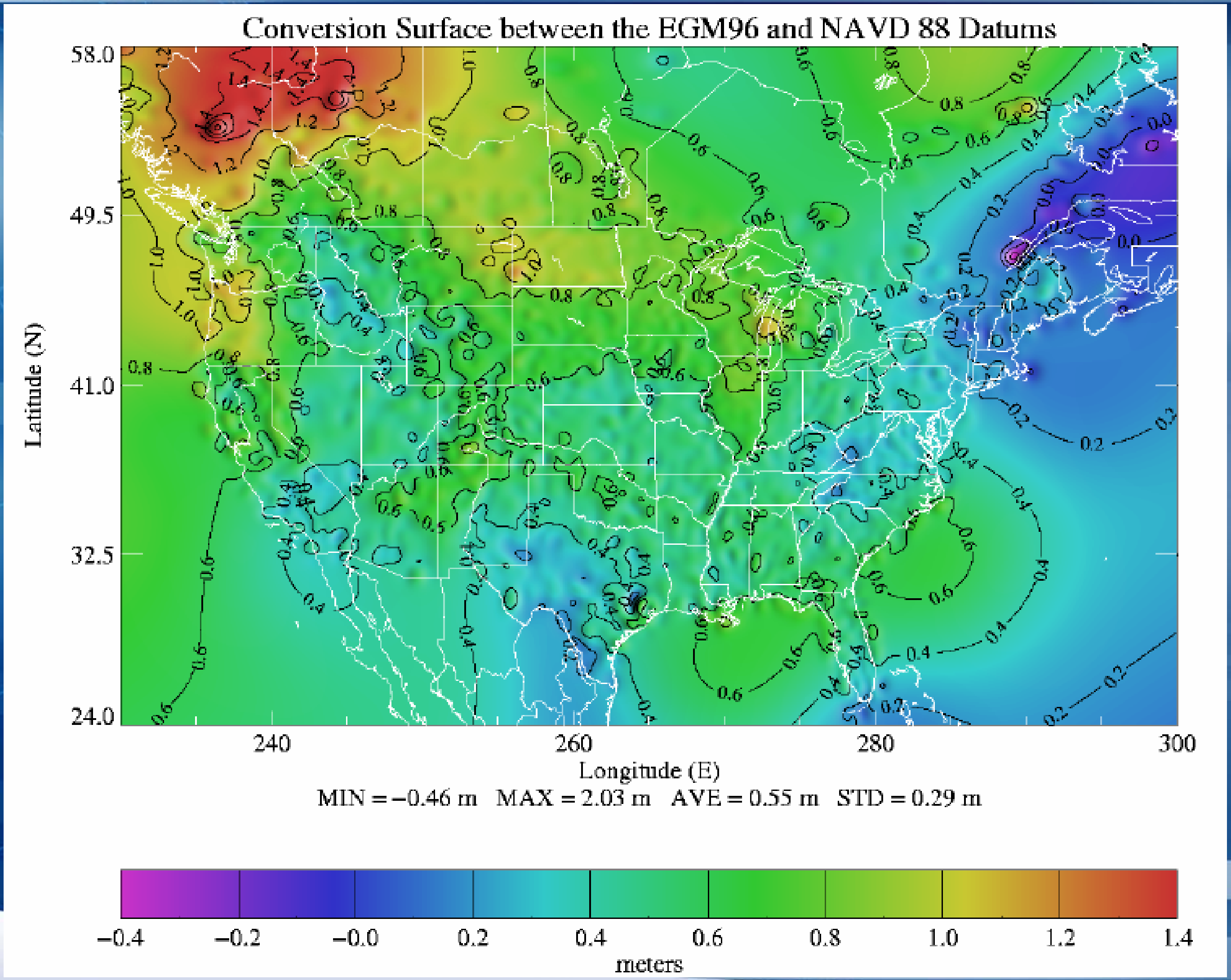
# High Resolution Geoid Models
# GEOID03 (vs. Geoid99)



- Relative to non-geocentric GRS-80 ellipsoid
- 2.4 cm RMS nationally when compared to BM data (vs. 4.6 cm)
- RMS ≈ 50% improvement over GEOID99 (Geoid96 to 99 was 16%)

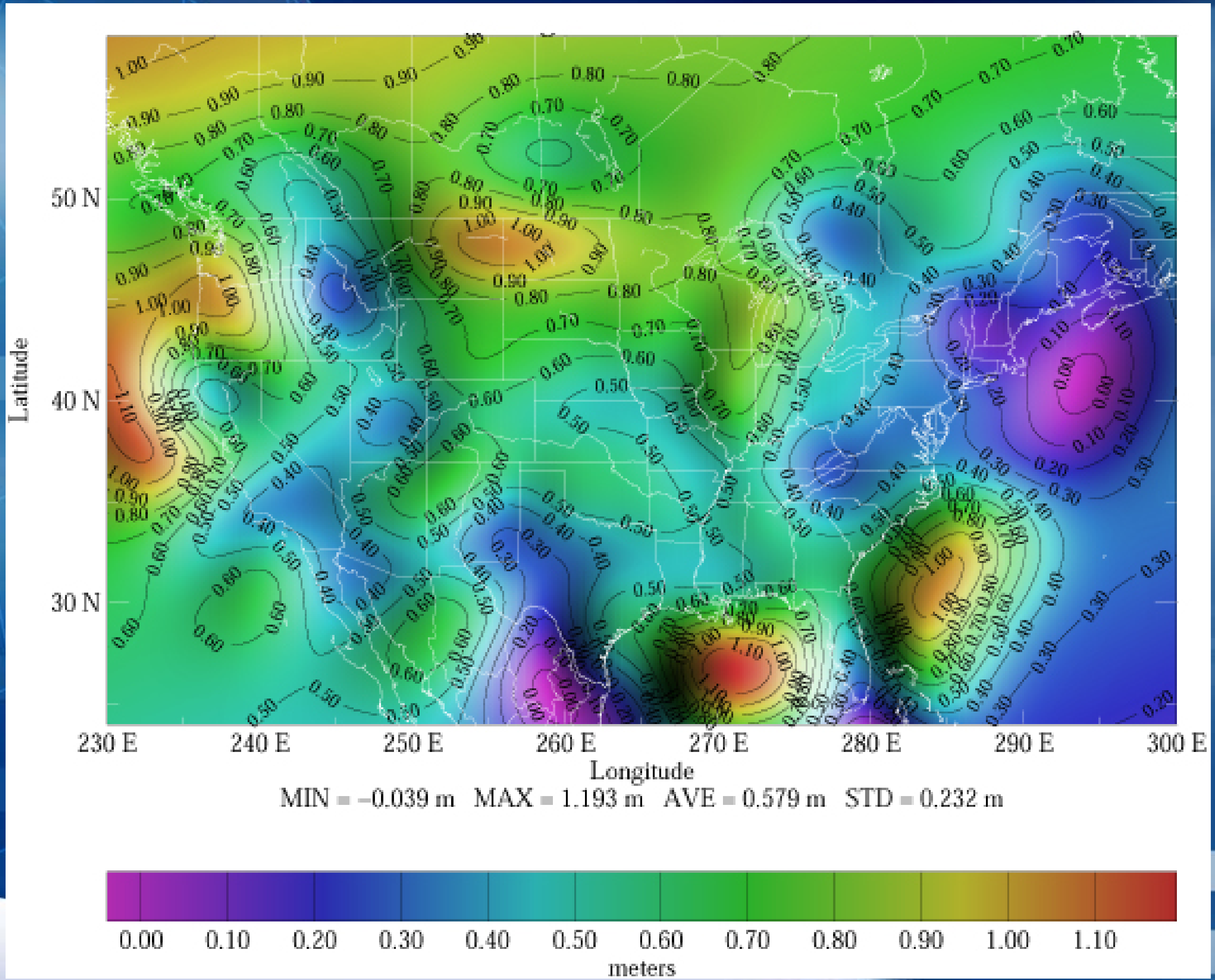
# GEOID03 Conversion Surface





# GEOID99 Conversion Surface

NATIONAL GEODETIC SURVEY




National Oceanic and Atmospheric Administration

# Sample Datasheet

NATIONAL GEODETIC SURVEY

```
 National Geodetic Survey,   Retrieval Date = DECEMBER 28, 2005
PL0314 ***********************************************************************
PL0314  DESIGNATION -  V 27
PL0314  PID         -  PL0314
PL0314  STATE/COUNTY-  MI/GRAND TRAVERSE
PL0314  USGS QUAD   -
PL0314
PL0314                        *CURRENT SURVEY CONTROL
PL0314  ___________________________________________________________________
PL0314* NAD 83(1994)-  44 39 02.41202(N)    085 46 04.27942(W)     ADJUSTED
PL0314* NAVD 88     -        257.838  (meters)      845.92   (feet)  ADJUSTED
PL0314  ___________________________________________________________________
PL0314  X           -     335,419.145 (meters)                     COMP
PL0314  Y           -  -4,532,722.532 (meters)                     COMP
PL0314  Z           -   4,459,971.520 (meters)                     COMP
PL0314  LAPLACE CORR-            5.18  (seconds)                   DEFLEC99
PL0314  ELLIP HEIGHT-          223.17  (meters)        (07/17/02)  GPS OBS
PL0314  GEOID HEIGHT-          -34.68  (meters)                    GEOID03
PL0314  DYNAMIC HT  -         257.812 (meters)      845.84  (feet)  COMP
PL0314  MODELED GRAV-     980,508.8   (mgal)                        NAVD 88
PL0314
```

H

h

N

# Sample Datasheet



- 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

# Sample Datasheet



```
PL0314
PL0314.The modeled gravity was interpolated from observed gravity values.
PL0314
PL0314;                   North         East     Units Scale Factor Converg.
PL0314;SPC MI C     -   149,194.606 5,888,865.237   MT  0.99992569   -0 59 23.3
PL0314;SPC MI C     -   489,483.62 19,320,424.01    FT  0.99992569   -0 59 23.3
PL0314;UTM  16      - 4,944,883.803   597,700.224   MT  0.99971738   +0 51 57.6
PL0314
PL0314!             -  Elev Factor  x  Scale Factor =   Combined Factor
PL0314!SPC MI C     -   0.99996501  x   0.99992569  =   0.99989070
PL0314!UTM  16      -   0.99996501  x   0.99971738  =   0.99968240
PL0314
PL0314                          SUPERSEDED SURVEY CONTROL
PL0314
PL0314  ELLIP H (02/03/97)  223.19   (m)                       GP(        ) 4 1
PL0314  NAD 83(1986)-  44 39 02.41257(N)    085 46 04.28315(W) AD(        ) 1
PL0314  NAD 83(1986)-  44 39 02.38347(N)    085 46 04.27988(W) AD(        ) 3
PL0314  NAVD 88 (09/30/91)  257.84   (m)          845.9    (f) LEVELING    3
PL0314  NGVD 29 (??/??/92)  257.915  (m)          846.18   (f) ADJ UNCH    1 2
PL0314
PL0314 Superseded values are not recommended for survey control.
PL0314.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
PL0314
```

# 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

# Sample Datasheet



```
     National Geodetic Survey,   Retrieval Date = DECEMBER 28, 2005
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PL0314  MODELED GRAV-     980,508.8   (mgal)                        NAVD 88
PL0314
```

H

h

N

NAVD88 – Ellip Ht + Geoid Ht = …

257.838 – 223.17 – 34.953 = -0.285 USGG2003

257.838 – 223.17 – 34.68 = -0.012 GEOID03

# 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 EGM06 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.

# Plans for Geoid Modeling at NGS (cont.)



- Long term goals are to define a cm-level accurate geoid height model valid for all of North America
  - Work is ongoing with the Canadians
  - Other nations joining in (Mexico/INEGI, etc.)
  - We likely will also adopt a vertical datum based on a refined geoid height model – the ultimate in Height Mod!
  - Conversion surface will provide means of transforming between this new datum and NAVD 88 – much as VERTCON does now between NGVD 29 and NAVD 88.
  - This maintains compatibility with archival data.
- To do this, several major areas need work:
  - Gravity database cleansing/analysis/standardization
  - Acquisition of additional data sets
  - Refinement of geoid theory

# Ongoing research areas



- We must have a consistent and seamless gravity field at least along the shorelines if not across all the U.S.
  - Use GRACE data to test long wavelength accuracy.
  - Use aerogravity to locate and possibly clean systematic problems in terrestrial or shipborne surveys (biases, etc.).
  - Determine and remove any detected temporal trends in the nearly 60 years of gravity data held by NGS. Ensure consistency of datums, corrections and tide systems.
  - This solves problems of current remove-compute-restore approach, which honors terrestrial data over EGM's.
- Exploration of utility of coastal/littoral aerogravity
  - Need a consistent gravity field from onshore to offshore.
  - Aids in database cleansing; also fills in coastal gaps.
  - Ties to altimetric anomalies in deeper water.
  - In conjunction with tide gauges & dynamic ocean topography models, this will aid in determining the optimal geopotential surface for the U.S. (Wo).

# Ongoing research areas (cont.)



- Must acquire data and models for outlying regions.
  - Definitely need surface gravity (terrestrial and shipborne) and terrain models for Guam, CNMI, American Somoa.
  - Desire to get such for nearest neighbors including Mexico, Caribbean nations, Central American nations, etc.
  - Also need to get any available forward geophysical models for all regions (such as ICE-5G for modeling the Glacial Isostatic Adjustment).
- GPS/INS evaluation of the gravity field.
  - GPS & IMU information were also collected on flights.
  - This data can be used to derive gravity disturbances and to estimate gravity anomalies.
  - It may be useful in benign areas for determining the gravity field. Possibly cheaper and more cost-effective than aerogravity (run with other missions?).

# Ongoing research areas (cont.)



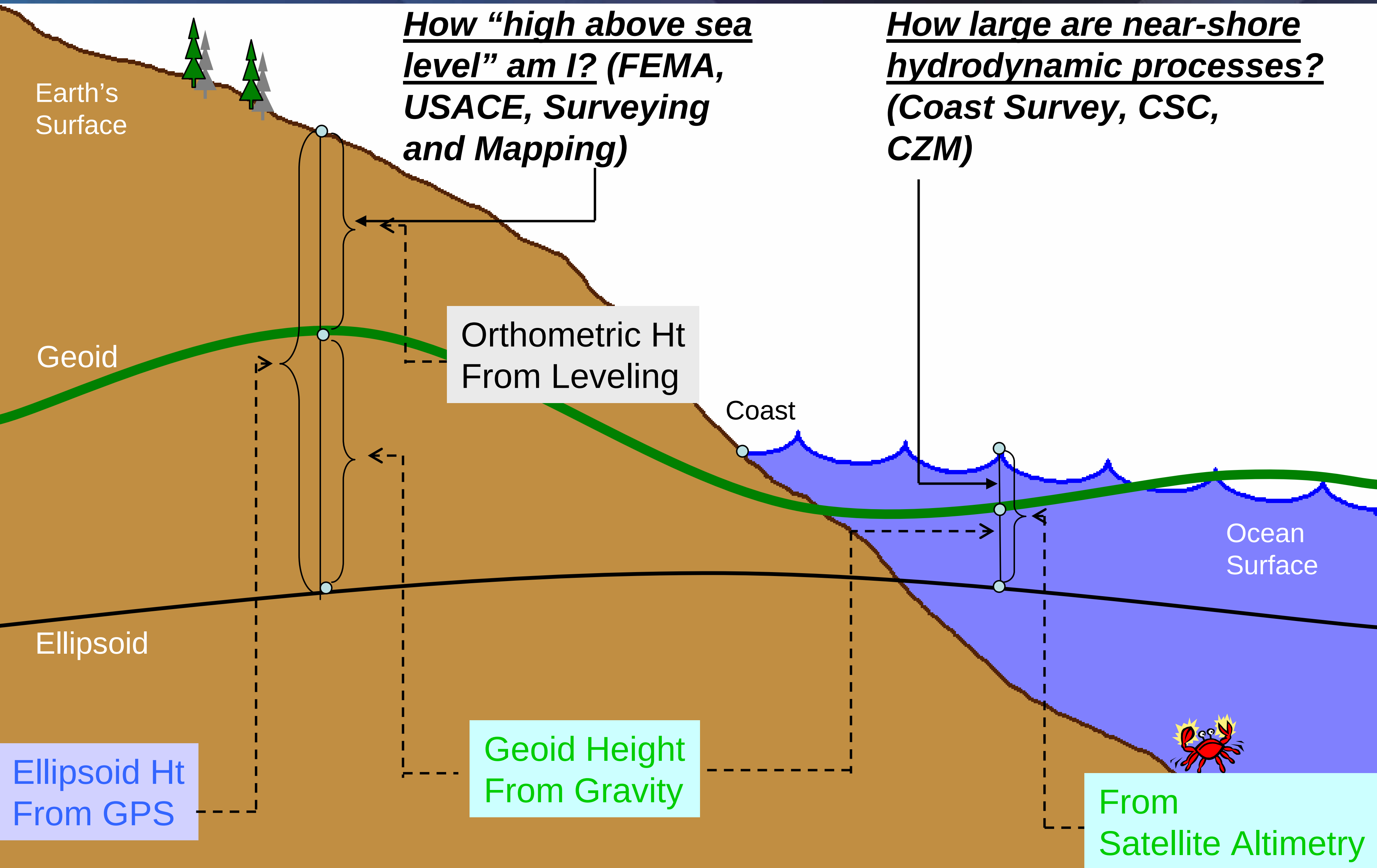
- Geodetic theory improvements.
  - Downward continuation of high altitude gravity observations.
  - Merging of gravity field components.
    - Current approach is remove-compute-restore.
    - Spectral merging of EGM, gravity and terrain data.
    - Would honor long wavelength (GRACE).
    - Retain character of the terrain and observed data.
  - Determination of geoid height using ellipsoidal coordinates instead of the spherical approximation.
  - Resolution of inner and outer zone effects from terrain on gravity observations.

# Gravity measurements help answer two big questions…



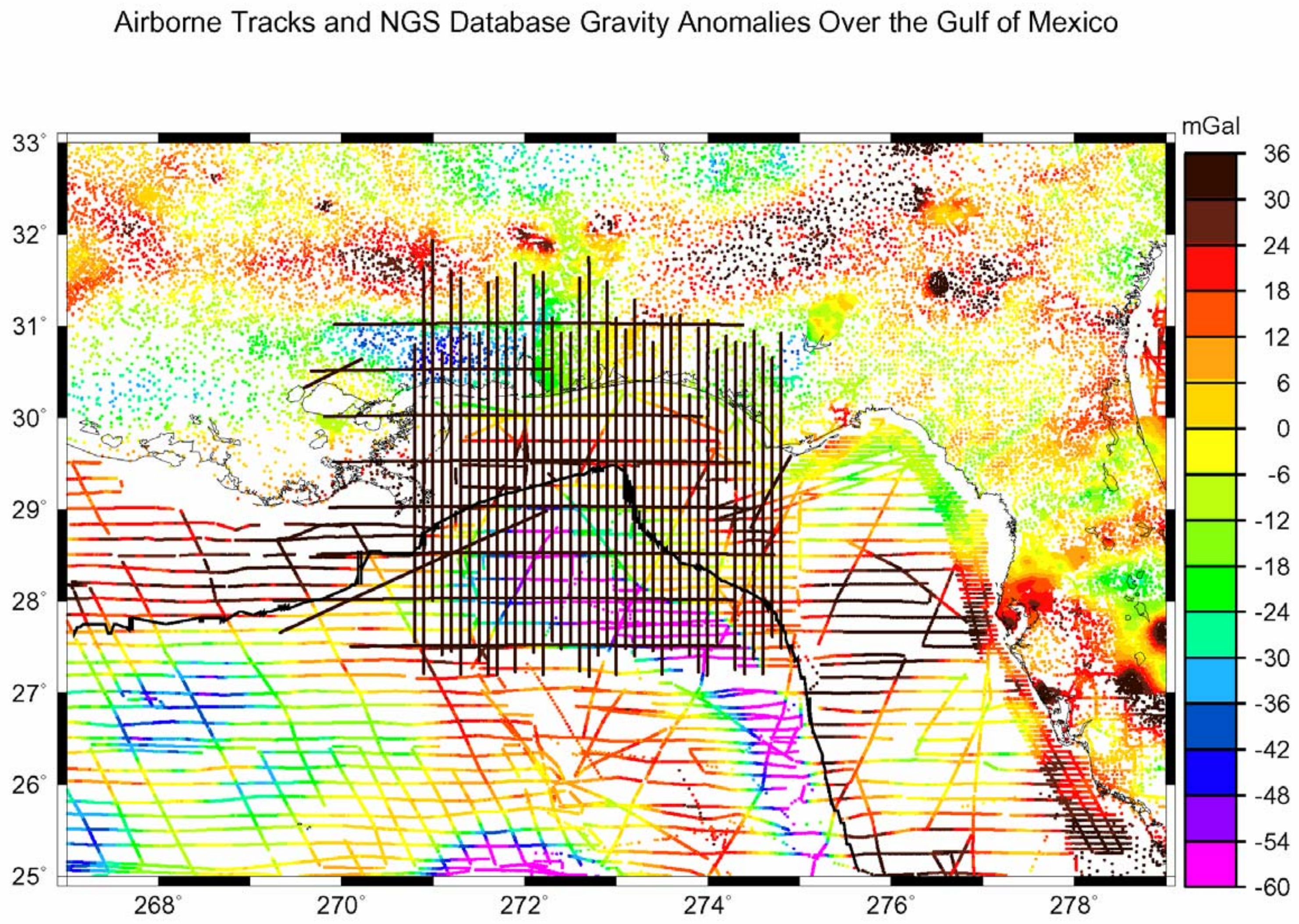
***How "high above sea level" am I? (FEMA, USACE, Surveying and Mapping)***

***How large are near-shore hydrodynamic processes? (Coast Survey, CSC, CZM)***



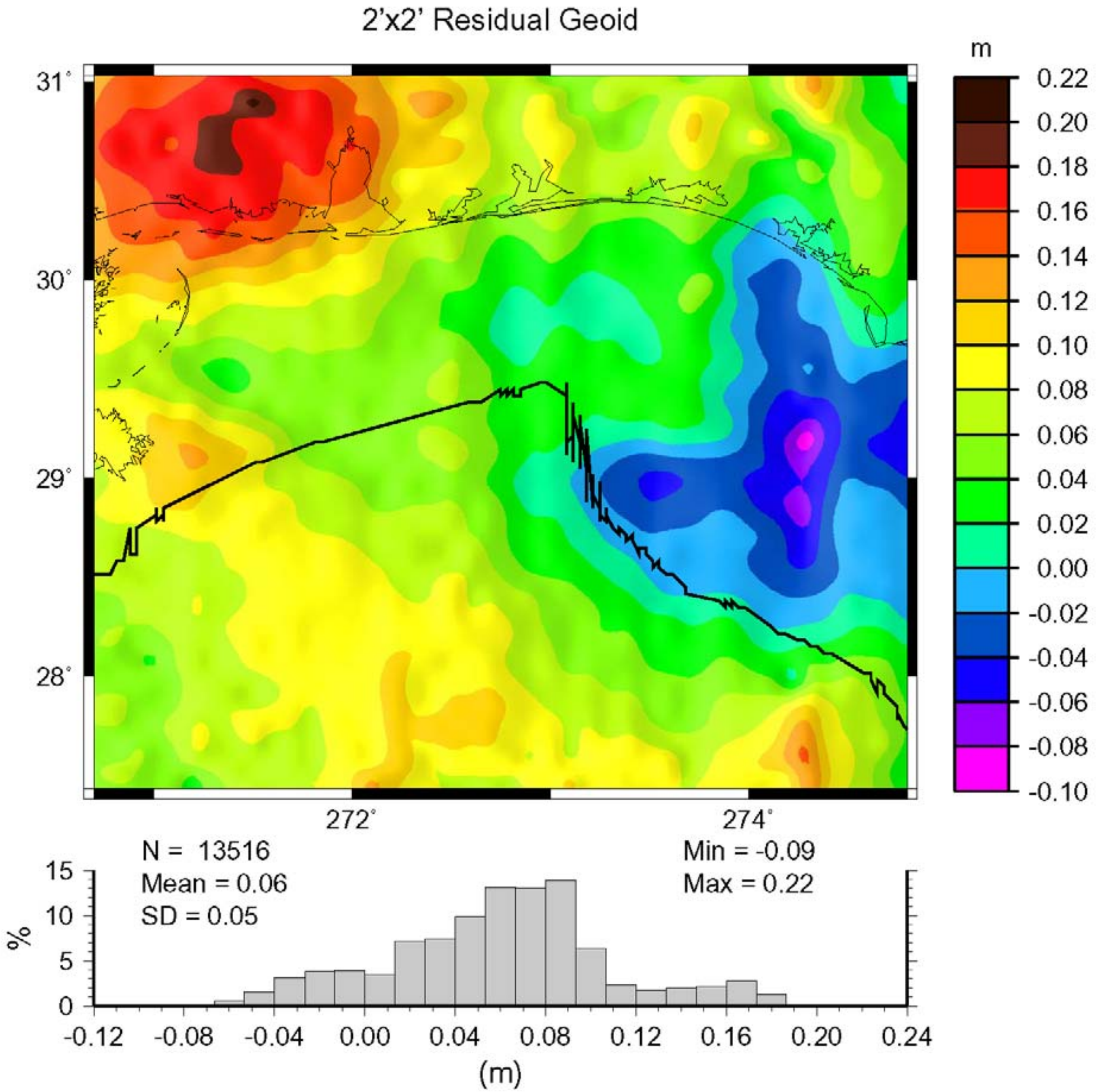
# Extent of Gravity and Data Collection Flights





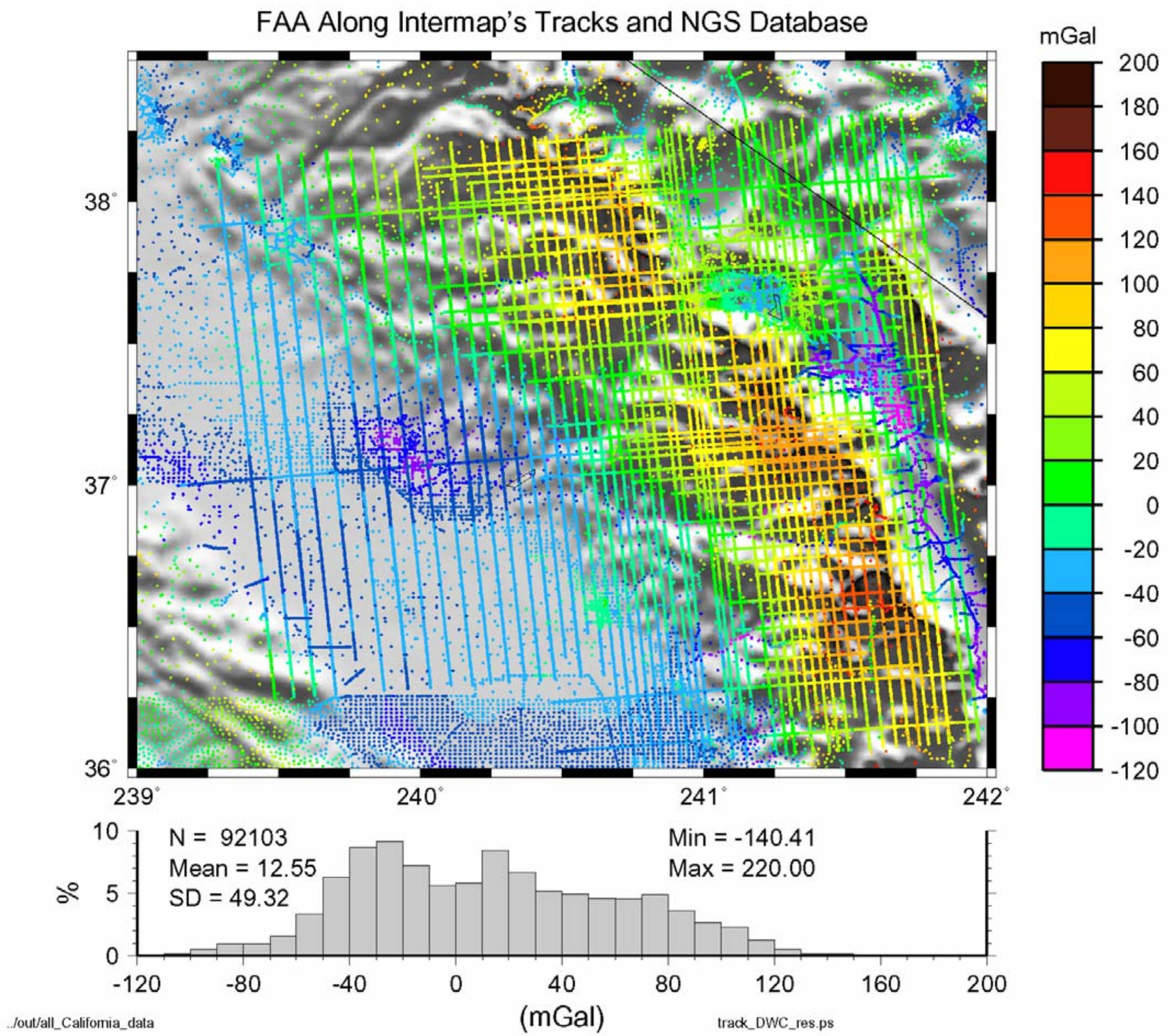
# Implied Geoid Changes

NATIONAL GEODETIC SURVEY



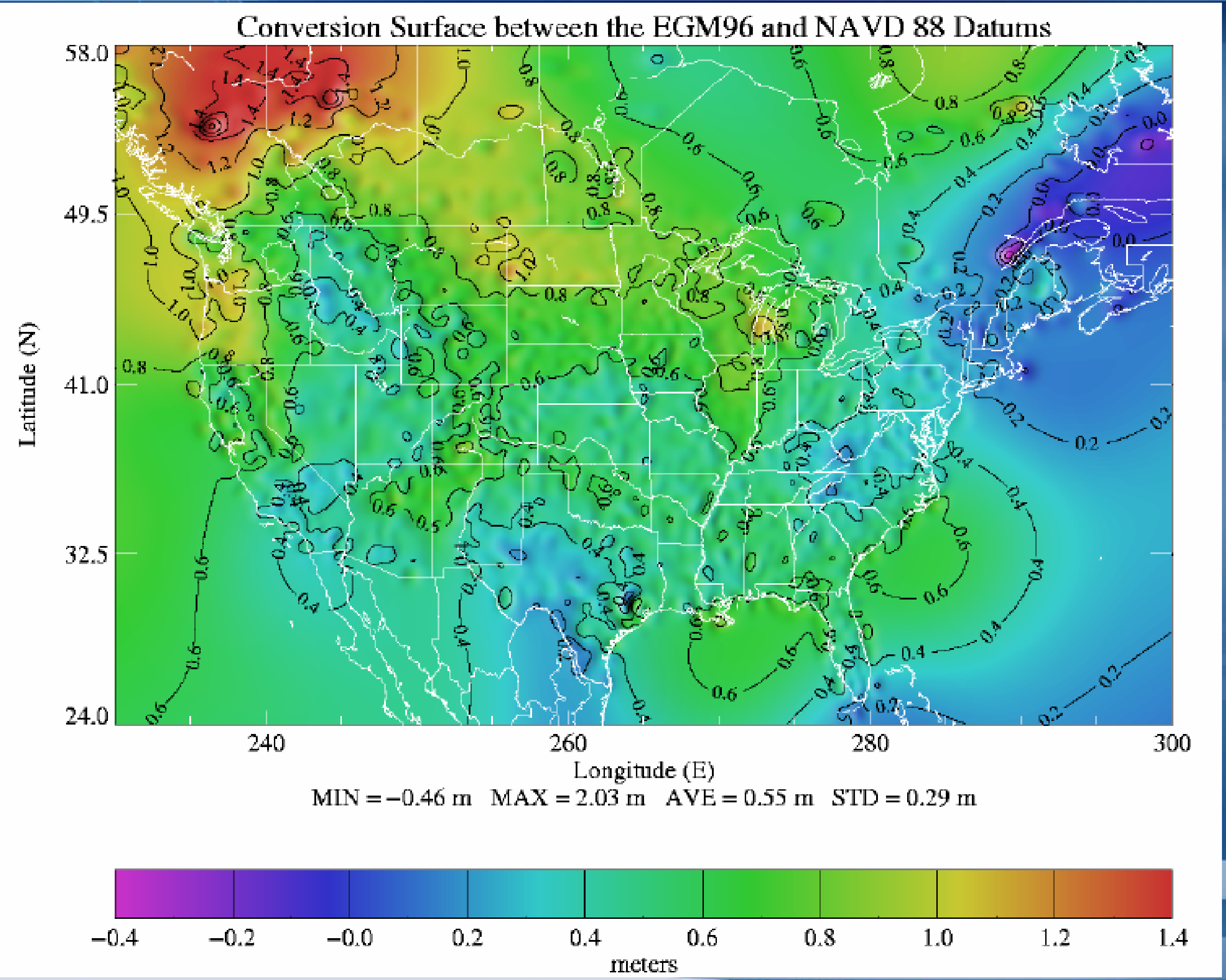
# GPS / INS-Derived Aerogravity vs. Surface Point Gravity in CA





# GEOID03 Conversion Surface

NATIONAL GEODETIC SURVEY




National Oceanic and Atmospheric Administration

# Expected Results



- A Consistent vertical datum between all U.S. states and territories as well as our neighbors in the region.
  - Reduce confusion between neighboring jurisdictions.
  - Local accuracy but national consistency.
- This provides a consistent datum for disaster management.
  - Storm surge, tsunamis, & coastal storms.
  - Disasters aren't bound by political borders.
- Heights that can be directly related to oceanic and hydrologic models (coastal and inland flooding problems).
- The resulting improvements to flood maps will better enable decision making for who does & doesn't need flood insurance.
- Updates to the model can be made more easily, if needed, to reflect any temporal changes in the geoid/gravity.
- Finally, offshore models of ocean topography will be improved and validated. These models will provide better determination of offshore water flow (useful for evaluating the movement of an oil slick).

# QUESTIONS?


Geoid Research Team:

- Dr. Daniel R. Roman, research geodesist
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- Dr. Yan Ming Wang, research geodesist
  yan.wang@noaa.gov
- Jarir Saleh, ERT contractor, gravity database analysis
- William Waickman, programming & database access

- Website: http://www.ngs.noaa.gov/GEOID/
- Phone: 301-713-3202