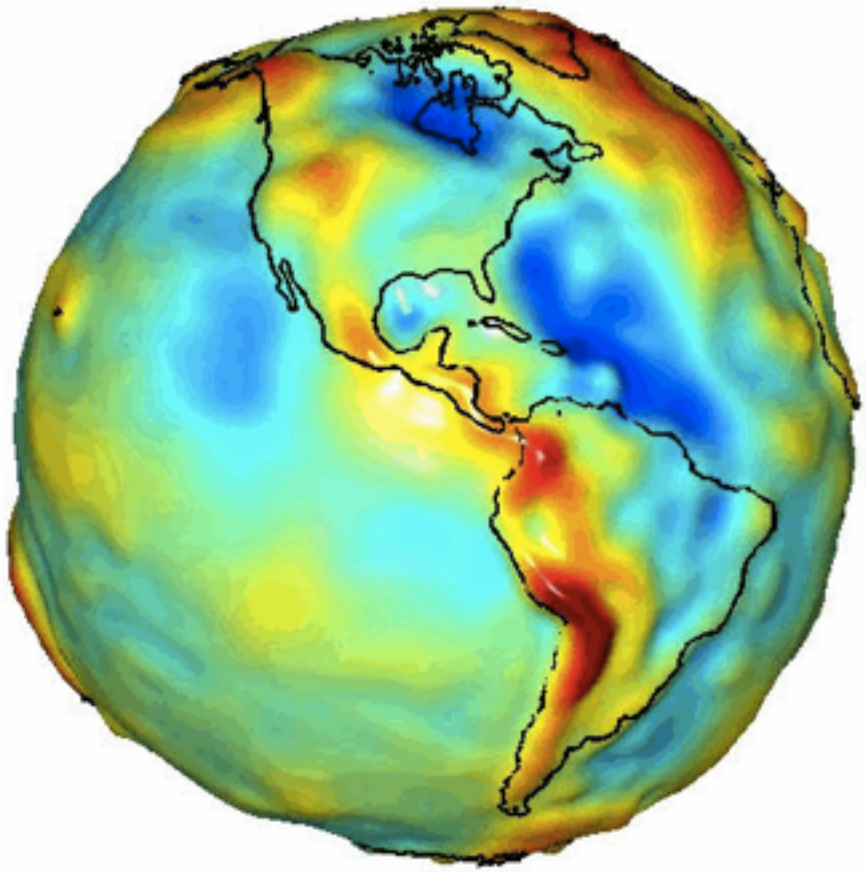
Classes 6 and 7 - Gravity and its importance to Geodesy



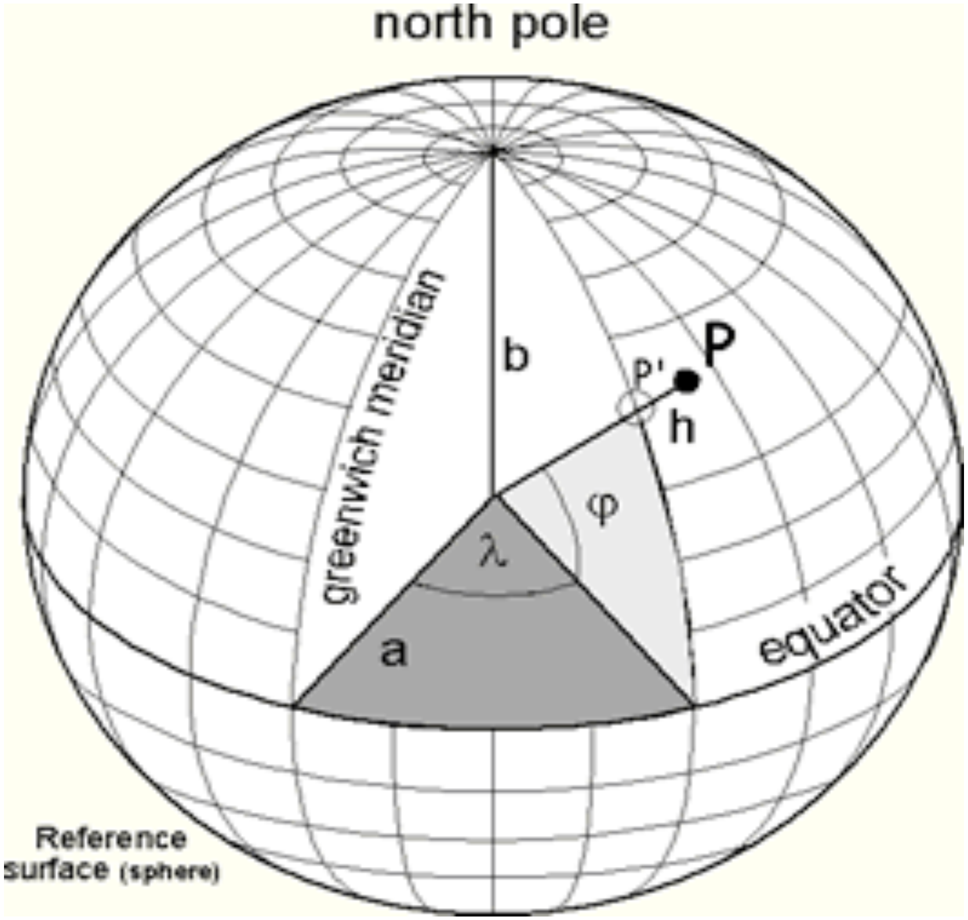
2 and 4 February 2010

Relative Gravity meters

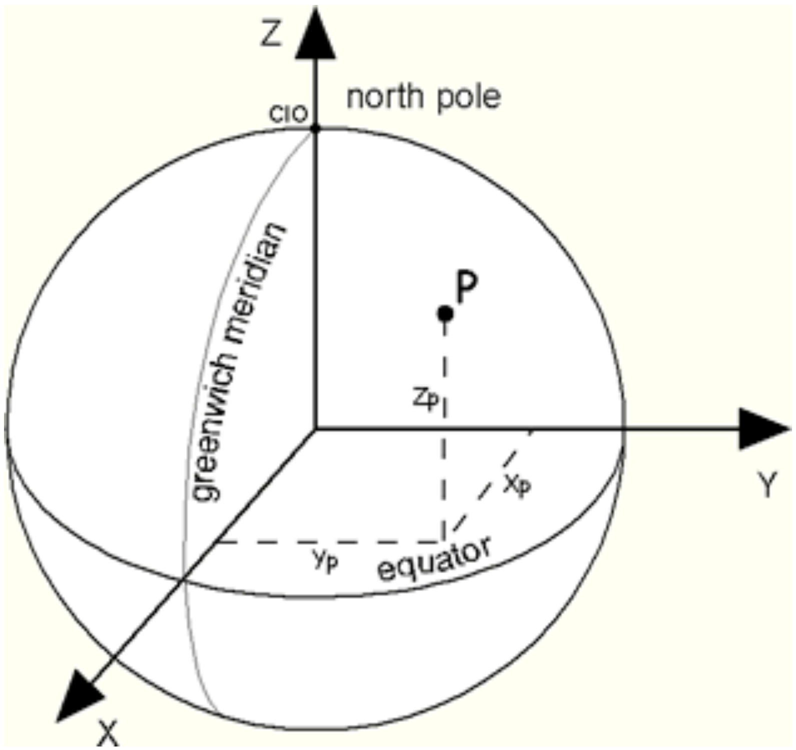
Schedule for this week

- Exam 1 this Thursday during Lab period
- You are responsible for material in Chapters 1-4 in text, homework as well as all lectures and labs to date.
- It is open book and access to the Internet will be needed.

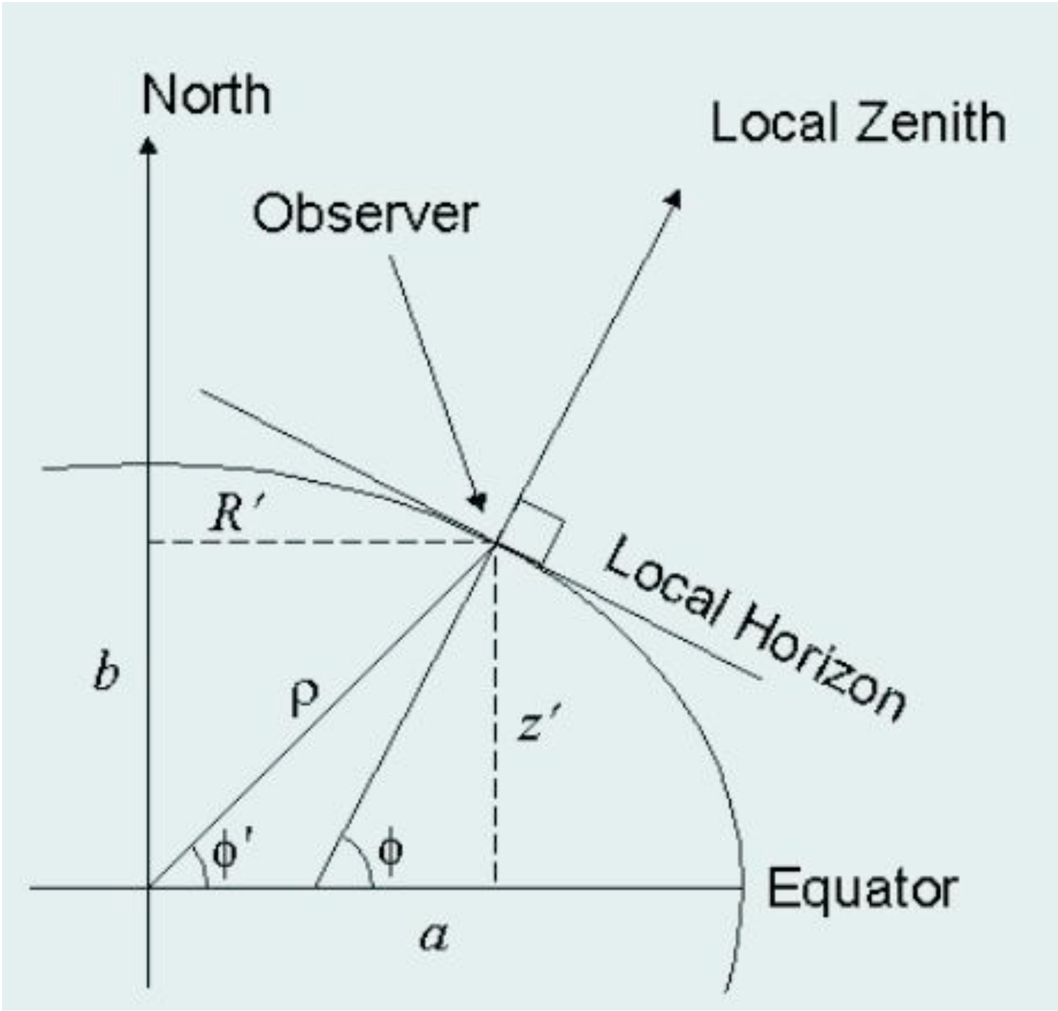
Natural Coordinates



Same Point in XYZ system



Geocentric v Geodetic Latitude



LLHs <-> XYZ

Geocentric relationship to XYZ

- One of the advantages of geocentric angles is that the relationship to XYZ is easy. R is taken to be radius of the sphere and H the height above this radius

$$\phi_c = \tan^{-1}(Z/\sqrt{X^2+Y^2})$$
$$\lambda_c = \tan^{-1}(Y/X)$$
$$R+H_c = \sqrt{X^2+Y^2+Z^2}$$

$$X = (R+H_c)\cos\phi_c\cos\lambda_c$$
$$Y = (R+H_c)\cos\phi_c\sin\lambda_c$$
$$Z = (R+H_c)\sin\phi_c$$

Problem with Geocentric

- Geocentric measures are easy to work with but they have several serious problems
- The shape of the Earth is close to an bi-axial ellipsoid (i.e., an ellipse rotated around the Z-axis)
- The flattening of the ellipsoid is ~1/300 (1/298.257222101 is the defined value for the GPS ellipsoid WGS-84).
- Flattening is (a-b)/a where a is the semi-major axis and b is the semi-minor axis.
- Since a=6378.137 km (WGS-84), a-b=21.384 km

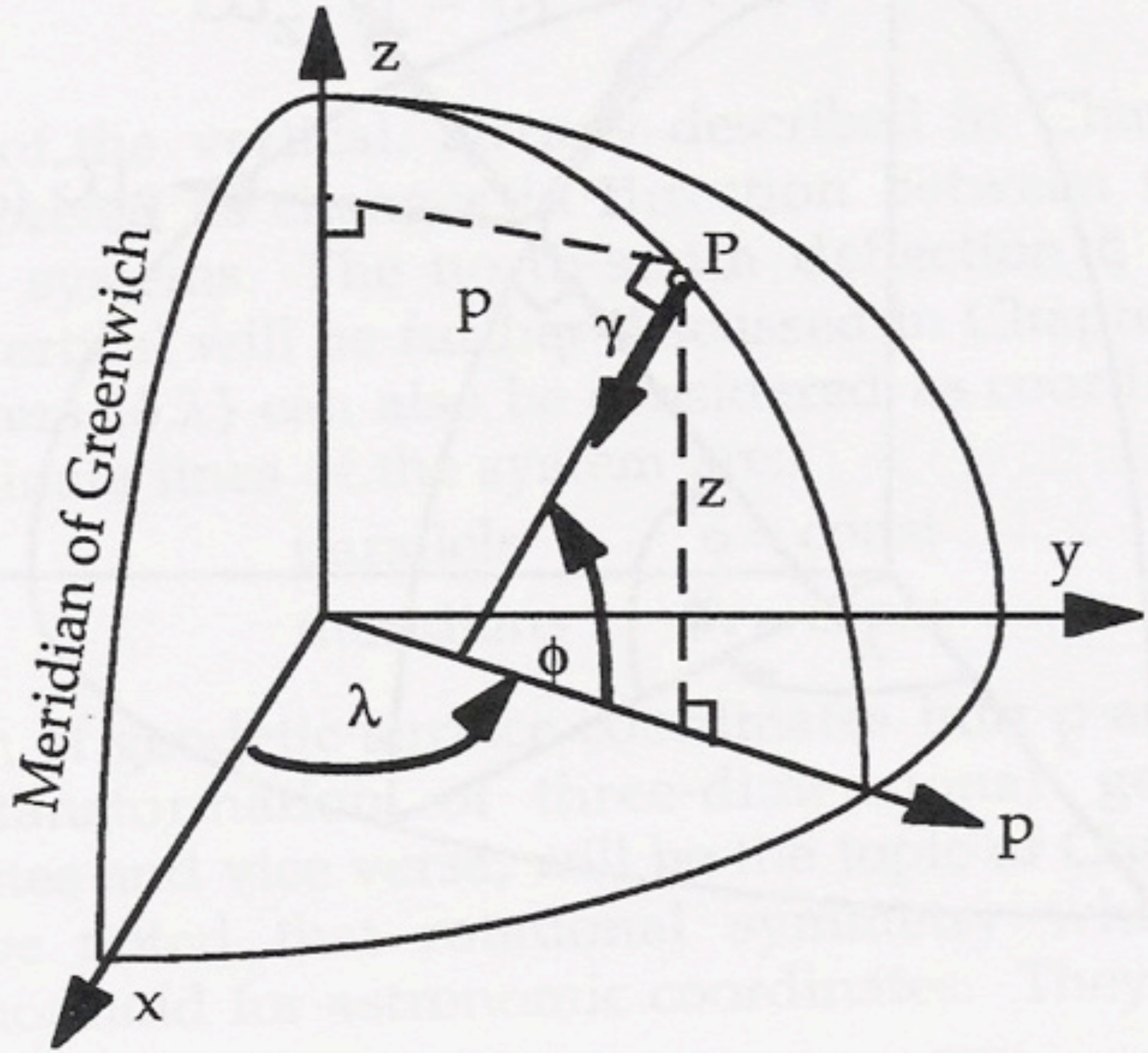
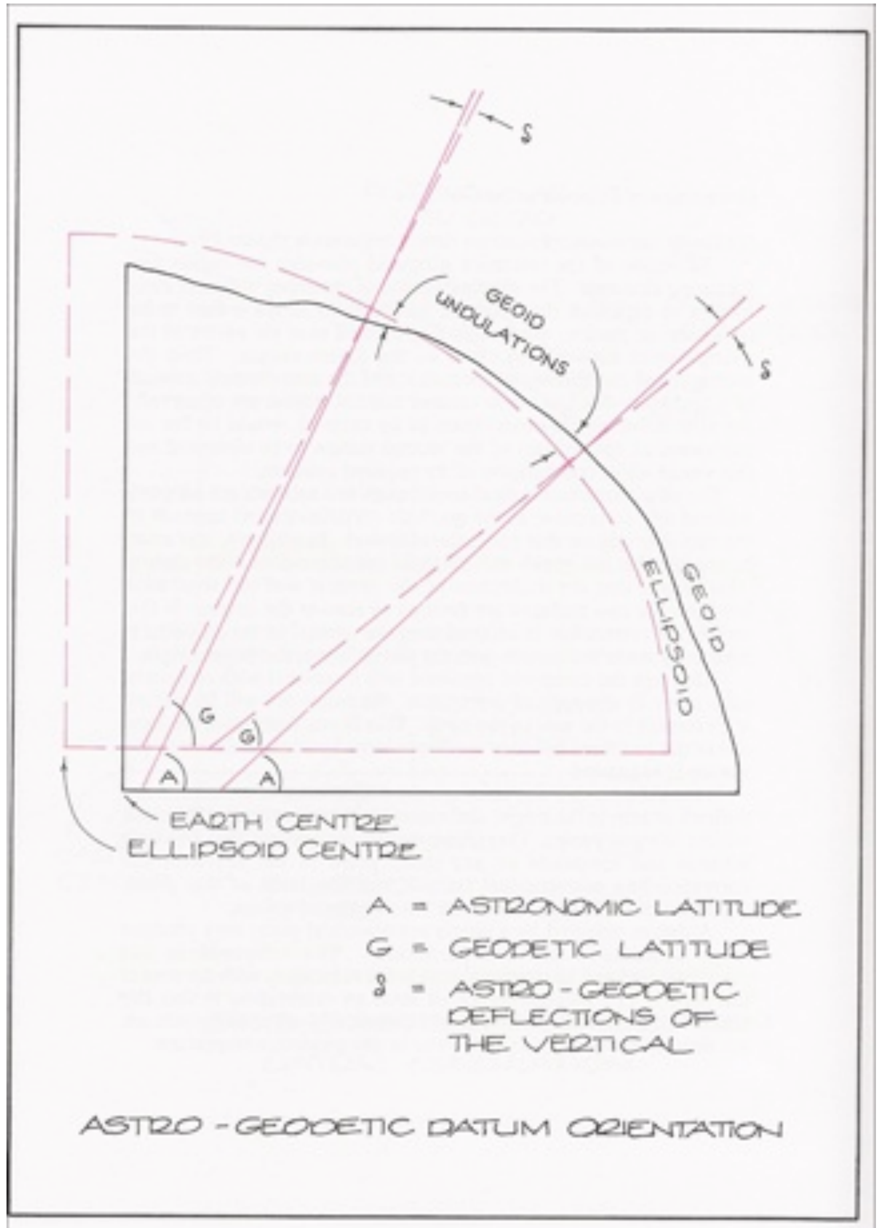


Figure 3.5 Geodetic Coordinates $\{\phi,\lambda\}$

The System of Natural Coordinates

- Axes are defined by meaningful directions: the gravity vector and of the spin axis of the Earth.
- Gravity vector defines the up-down direction
  - Orthogonal to a level surface.
- There is a difference between the gravity vector and normal to ellipsoid.



Geodetic Reference System 1980 (GRS80)

adopted by the International Association of Geodesy (IAG) during the General Assembly 1979. Principal parameters are:

parameter	symbol	value
defining constants		
equatorial radius of the Earth	a	6378137 m
geocentric gravitational constant (including the atmosphere)	GM	$3986005 \cdot 10^{8}\ m^{3}s^{-2}$
dynamical form factor (excluding permanent tides)	J_2	$108263 \cdot 10^{-8}$
angular velocity of the Earth	w	$7292115 \cdot 10^{-11}$ rad s^{-1}
derived geometrical parameters		
semiminor axis (polar radius)	b	6356752.3141 m
first excentricity	e^2	0.00669438002290
flattening	f	1 : 298.257222101
mean radius	R_1	6371008.7714 m
radius of sphere with same surface	R_2	6371007.1810 m
radius of sphere with same volume	R_3	6371000.7900 m
derived physical parameters		
normal potential at ellipsoid	U_0	$62636860.850\ m^{2}s^{-2}$
Normal gravity at equator	g_e	$9.7803267715\ m\ s^{-2}$
Normal gravity at pole	g_p	$9.8321863685\ m\ s^{-2}$

---

wb 09/1999 Comments & suggestions

Universal Law of Gravitation

- Newton formulated the law (1687) to reflect the attraction of two point masses separated by a distance.
    - $f = G^* [(m^*m')/l^2]$
  - (f is force, m and m' are point masses, l is distance and G is Newton's gravitational constant)
- Currently accepted value for G
  - $6.67259 \times 10^{-11} m^3 kg^{-1} s^{-2}$

More mind-numbing detail…

- At latitude p, a conventional value of the acceleration of gravity at sea level is given by the **International Gravity Formula,**
  - $g = 978.0495\ [1 + 0.0052892 \sin^2(p) - 0.0000073 \sin^2(2p)]$ cm per second per second (cm s^{-2}).
- The mean Earth gravity is about 981 000 mGal (the well-known 9.81 m/s^2), varies from 978,100 mGal to 983,200 mGal from Equator to pole due to the Earth's flattening and rotation.

Gravitational Acceleration

- The magnitude of acceleration (b) due to the Earth's mass on the surface using a spherical geometric reference surface (R) is:
  - $b = GM/R^2$

```
>> b = 398600.5e9/6371000^2

b =

    9.8203
```

Centrifugal Acceleration

- Direction is always perpendicular outward from the spin axis.
- It is a function of *angular velocity* of the Earth squared and the distance from the point of interest on the surface of the sphere to the axis of rotation.
- ω = 7292115e-11rad sec-1
- We can compute this value as ratio of degrees over time.

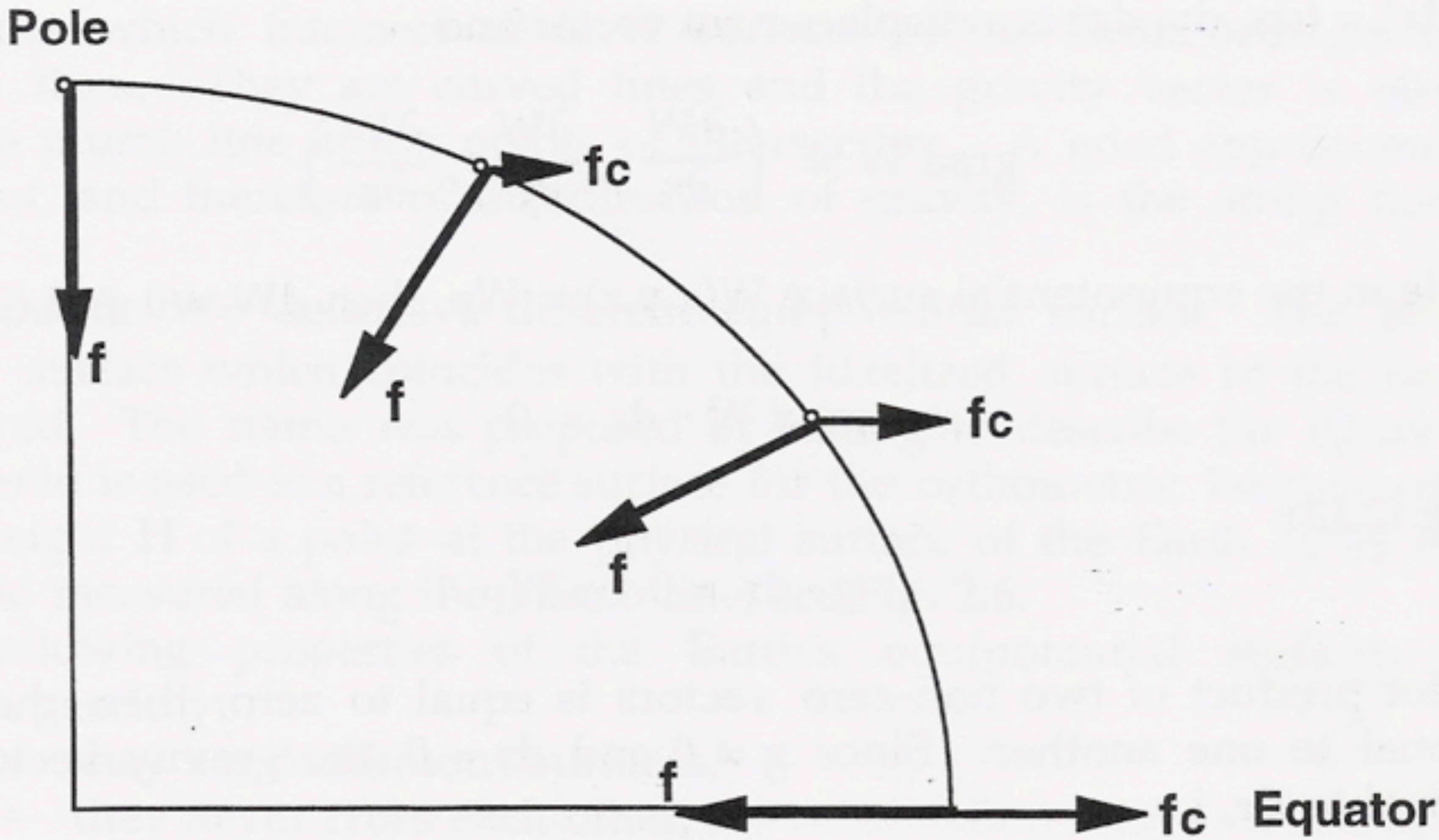


Figure 2.5 Interaction of gravitation f and centrifugal acceleration f_c

Gravitational Attraction

- Is the vector sum of gravitational and centrifugal acceleration.
- The actual acceleration of gravity varies from place to place, depending on latitude, altitude, and local geology.
- By agreement among physicists, the standard acceleration of gravity (gn) is defined to be exactly 9.80665 meters per second per second (m s-2), or about 32.174 05 feet per second per second.

Magnitude of centrifugal acceleration

- Varies from equator to poles.
- Compute magnitude by velocity squared times the distance from the point of interest to the spin axis.

```
>> omega = 7292115e-11;
>> R = 6371000;
>> CentrifAccelEquator = omega^2*R

CentrifAccelEquator =


    0.0339
```

Gravity and Geodesy

- Defines a plumb line (local vertical) defined by gravity.
- Gravity also serves as an important reference surface. It is the level surface that is perpendicular to the plumb line at all points.

Gravitational Potential

- Magnitude of the potential is the work that must be done by gravity to move a unit mass from infinity to the point of interest.
- Is **dependent** on position within the gravitation field.

Equipotential Surfaces

- Surface having constant gravity potential.
  - Also known as level surfaces or ***geopotential surfaces***.
- Surfaces are perpendicular at all points of the plumb line (gravity vector).
- **Potential field is a scalar field from which the vector gravity field can be found.**
- A still lake surface is an equipotential surface.
  - **It is not horizontal but curved**.

Properties of equipotential surfaces

- They are closed continuous surfaces that never cross one another.
- They are formed by long radius arcs. Generally without abrupt steps.
- They are convex everywhere.

$$\int_{\infty}^{p} \vec{f} d\vec{l}$$

$\vec{f}$ is the force dependent upon position within the force field. $d\vec{l}$ is an element of distance. Note that the potential is expressed in units of work and that it is path independent.

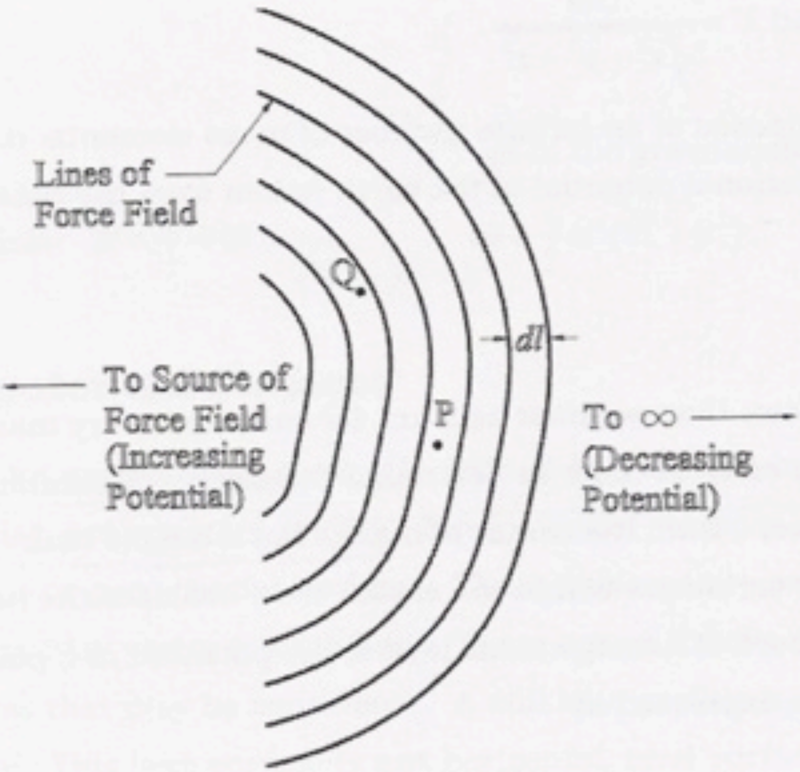


Figure 4.2 Positions of Points P and Q in a Force Field.

The change in potential (work required to move) from point P to point Q within a force field is:

Image from Featherstone, W, “Height Systems and Vertical Datums” Spatial Science, Vol 51 No. 1, June 2006

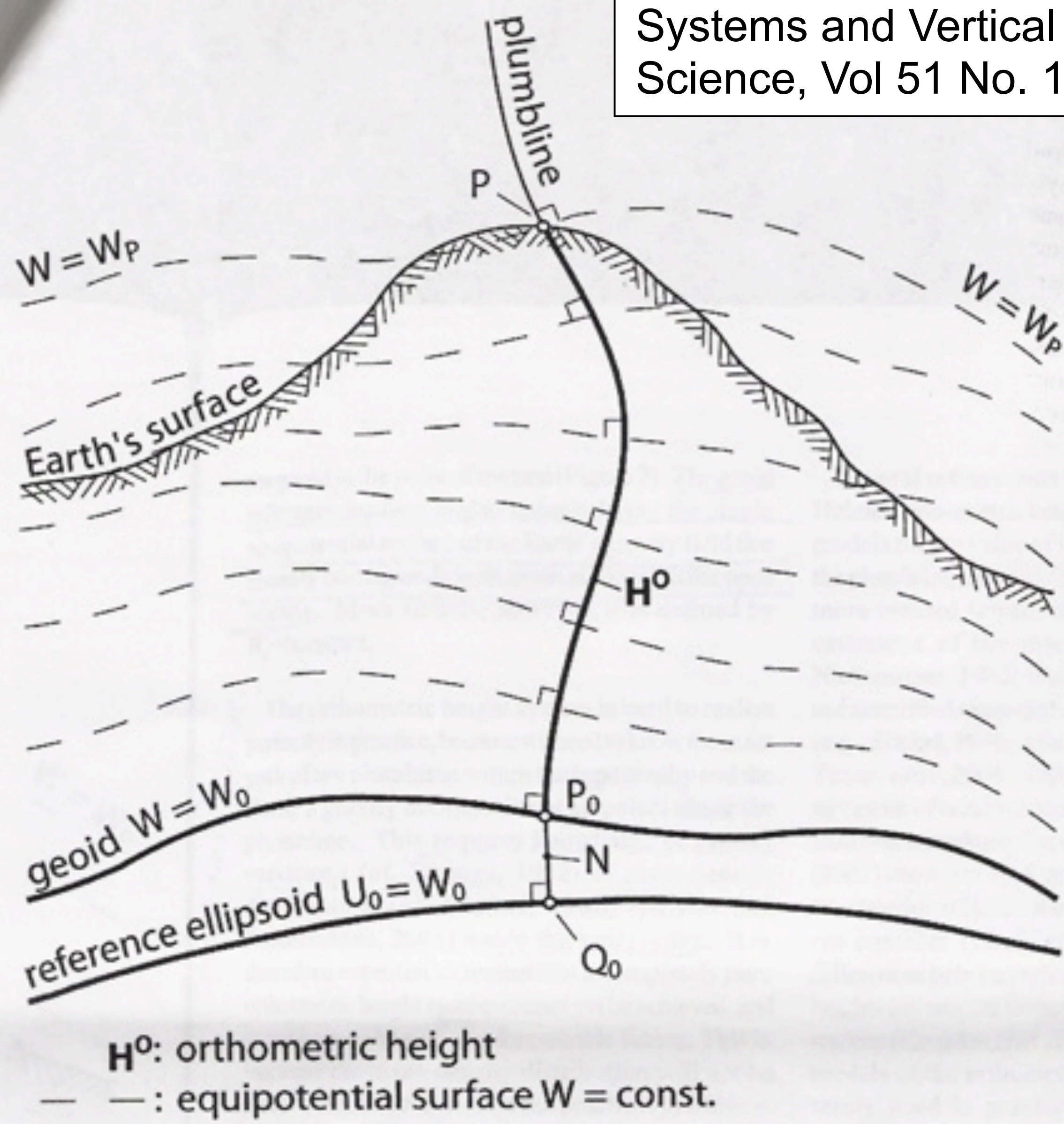


Figure 2. *The orthometric height H^o: a curved-line distance reckoned along the plumbline from the point P_0 on the surface of the geoid to the point of interest P. The geoid height N: a straight line distance reckoned along the ellipsoidal surface normal from the point Q_0 on the surface of the ellipsoid to the point P_0 on the surface of the geoid (Note that the curvature of the equipotential surfaces and plumblines has been exaggerated)*

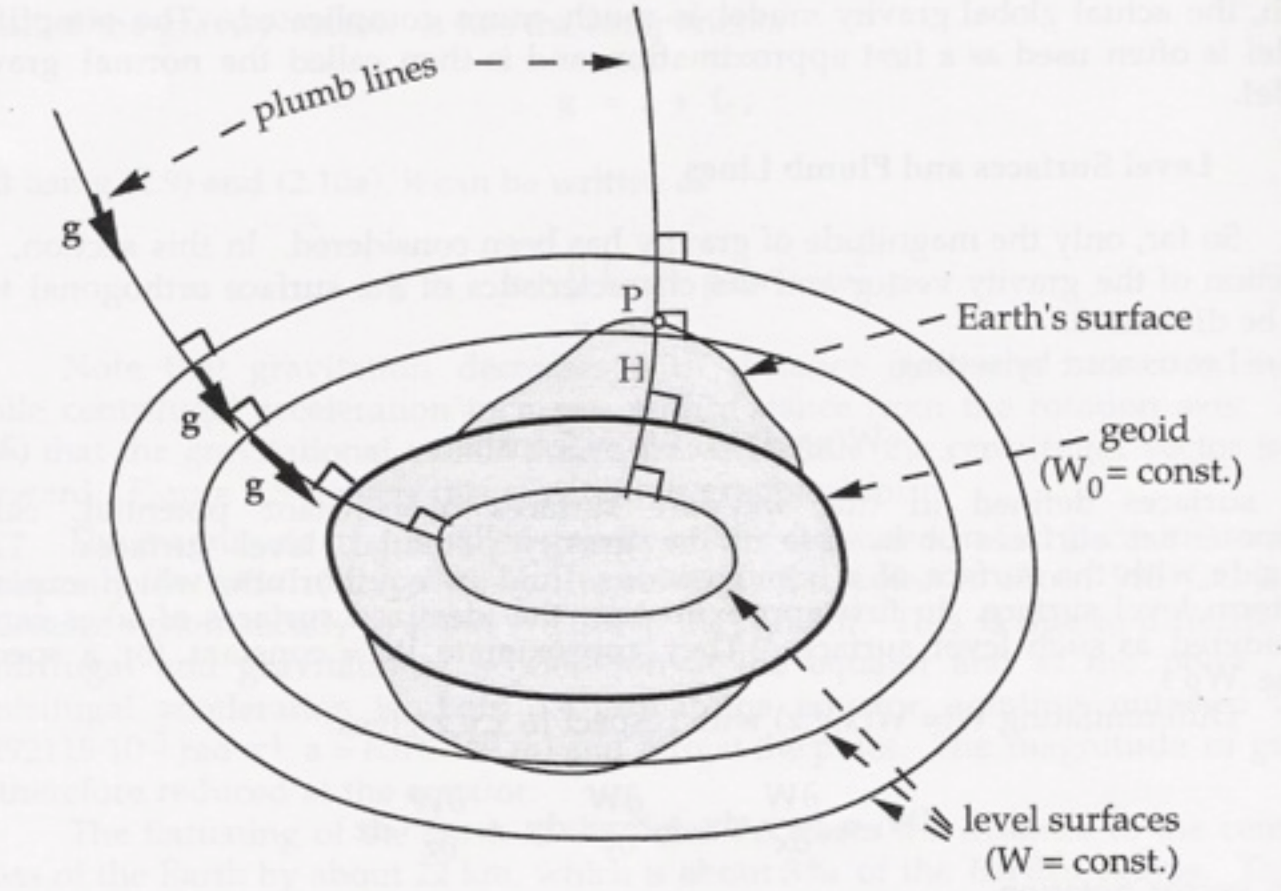


Figure 2.6 Level Surfaces, Plumb Lines, Geoid

Gravity defines the plumb line – the local vertical

What is Geodesy?

- "Geodesy is the discipline that deals with the measurement and representation of the earth, including its gravity field, in a three-dimensional time varying space."
  - definition adopted by the National Research Council of Canada in 1973. (Vanicek, P.K. and Edward Krakiwsky, E.(1986) Geodesy: The Concepts. Elsevier).

Another definition

- "The task of geodesy is the determination of the potential function W(x,y,z)" i.e. of the gravity potential of the Earth.
  - By Heinrich Bruns (1878)
- Both definitions indicate the linkages between positioning and gravity field determination.

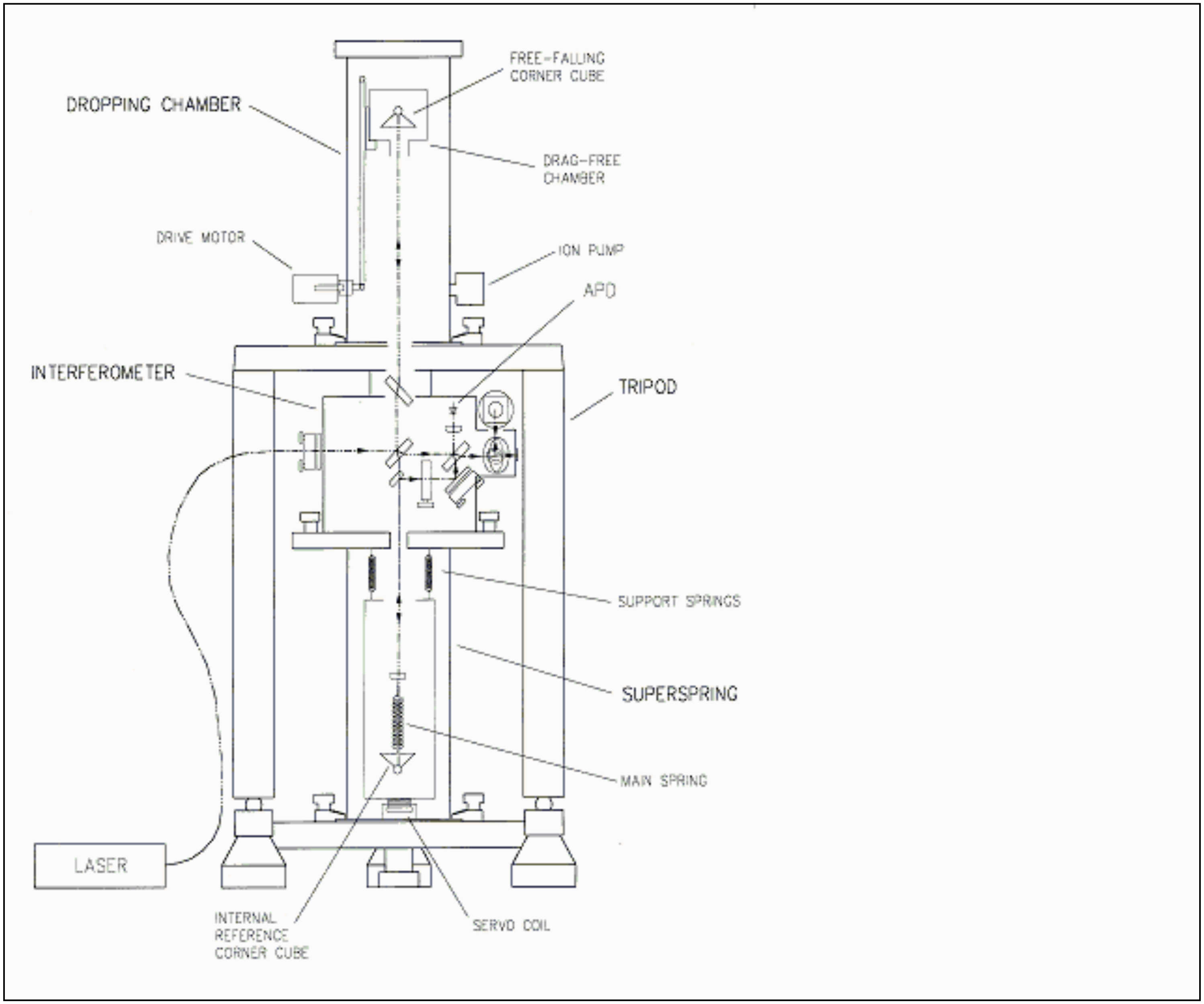
Integrated Geodesy

- Also called “Operational Geodesy”
- Integrated geodesy is a method in which a wide variety of surveying measurements are modeled in terms of geometric positions and the earth’s geopotential.
  – Both geometric and gravimetric data are simultaneously estimated using Least Squares.

Absolute Gravity Meters

How does it work?

- Motion of a test mass free falling in a vacuum is interferometrically measured with respect an inertial reference.
- Controlled carriage assembly releases the test mass (a corner cube retroreflector mounted in an aluminum housing).
- The inertial reference is another corner cube retroreflector mounted on a force feedback long period (60sec) seismometer.
- Non-gravitational forces are minimized (air drag, electrostatics, and eddy current damping).



FREE-FALLING CORNER CUBE
DROPPING CHAMBER
DRAG-FREE CHAMBER
DRIVE MOTOR
ION PUMP
APD
INTERFEROMETER
TRIPOD
SUPPORT SPRINGS
SUPERSPRING
MAIN SPRING
LASER
INTERNAL REFERENCE CORNER CUBE
SERVO COIL

Gravity change

- FG5 accuracy:
  - Instrument 1.1 μGals
  - Environmental: 1.5 μGals
  - Observational error: ~0.4 μGals
  - RMS of above at instrument height (131 cm): 1.9 μGals
  - RMS with relative transfer to mark or excenter: 3 to 8 μGals

- +3 μGals corresponds to
  - -1 cm elevation change
  - +7½ foot rise in water-table
  - GPS to resolve ambiguity
- Can also measure
  - magma insertion
  - sea level change (with tide record comparisons)
  - glacial ice mass change

Set Standard Deviation = 6.8 uGal

Micro-g Solutions, Inc.

MAG
Operational Test

ERIE CU (11-12 Aug 98)
MAG-1, Reference Ht. = 100 cm

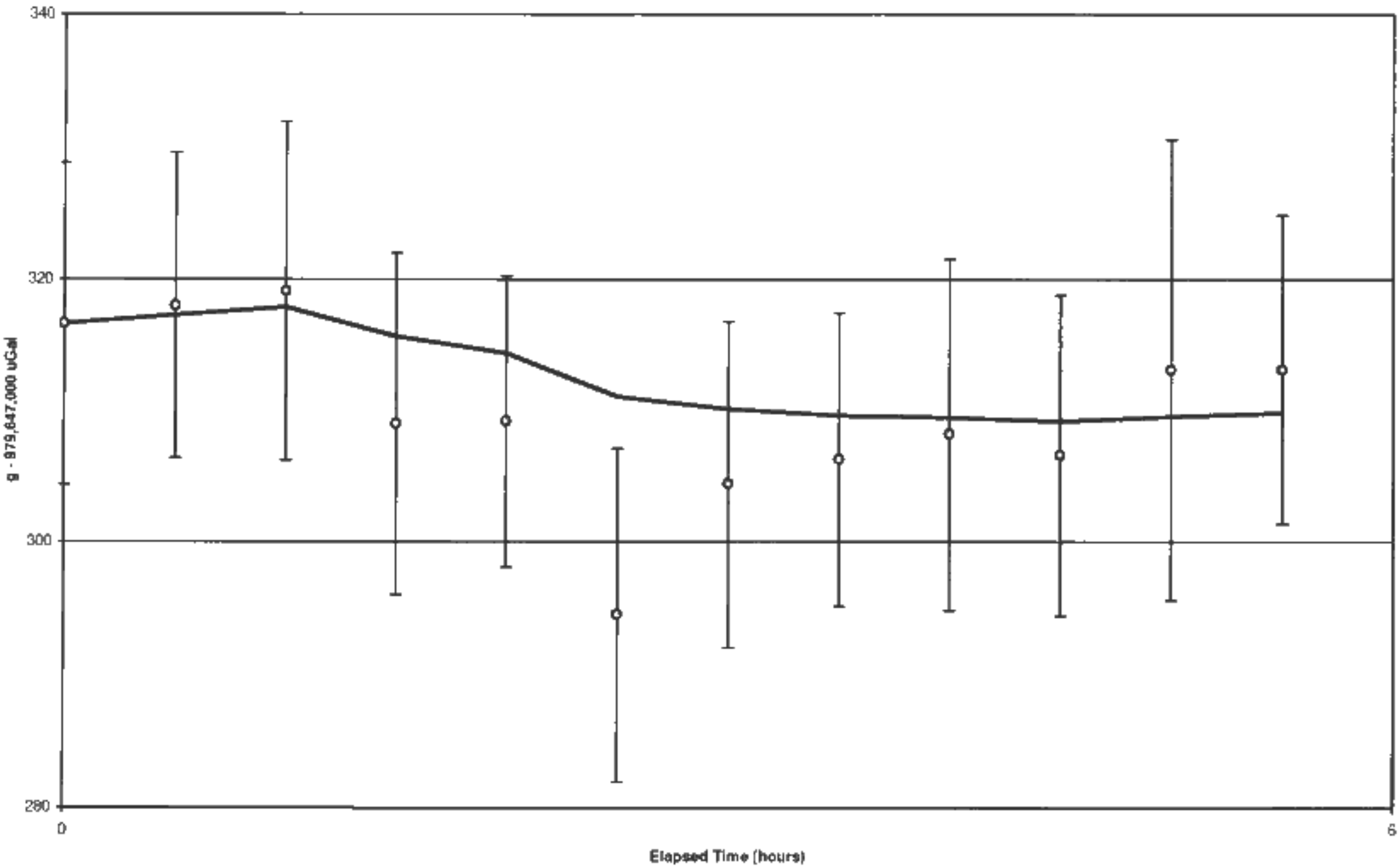
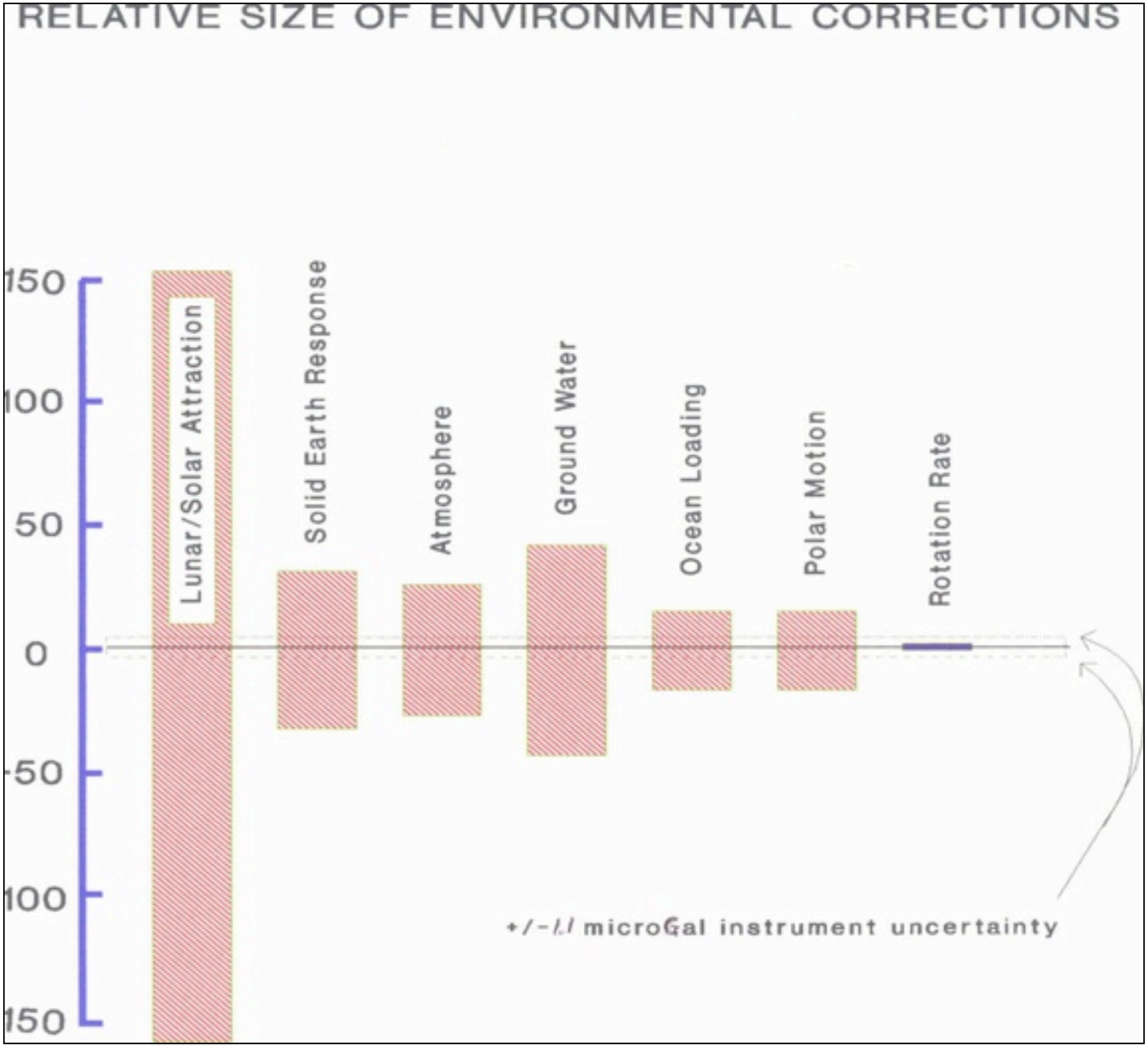
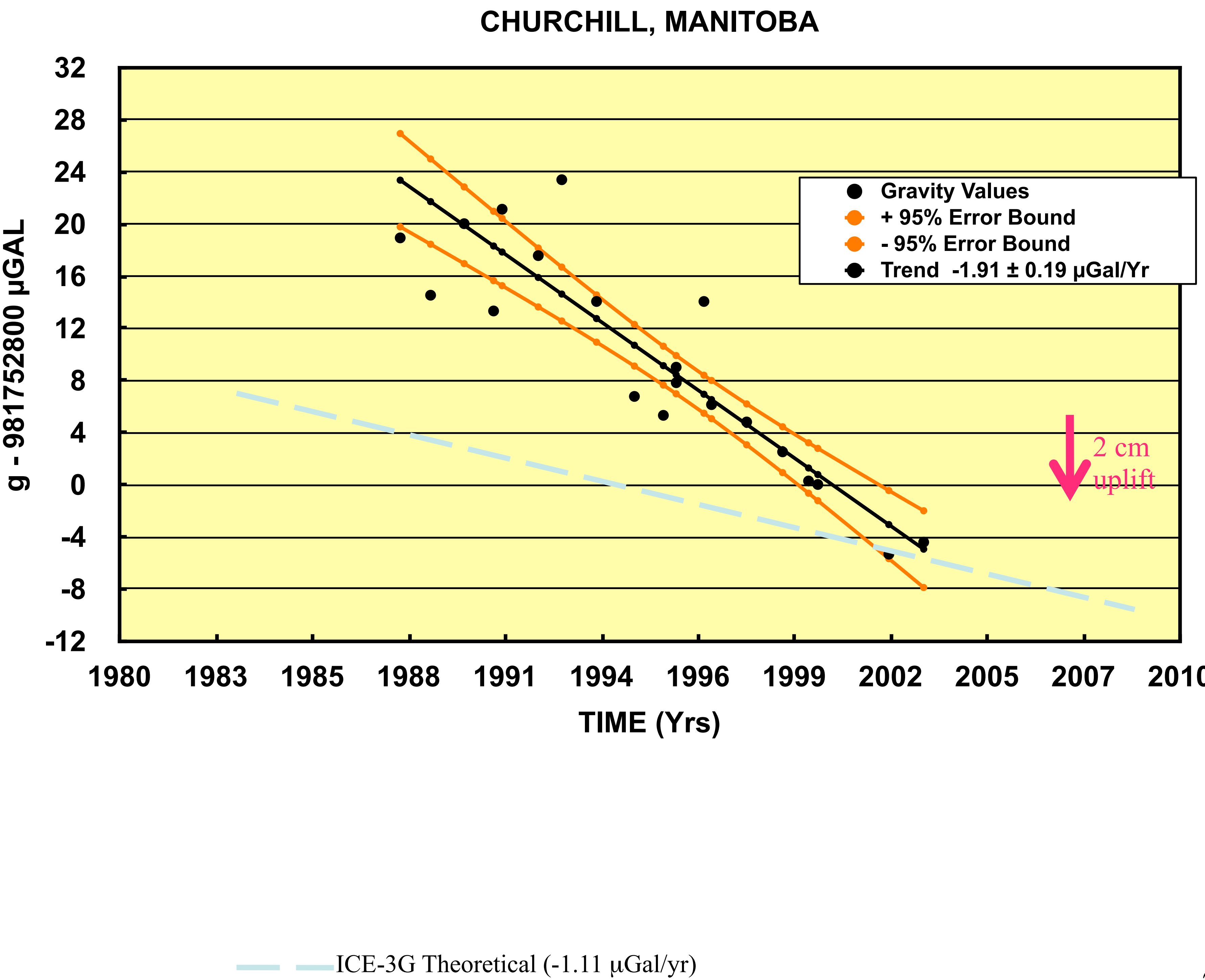
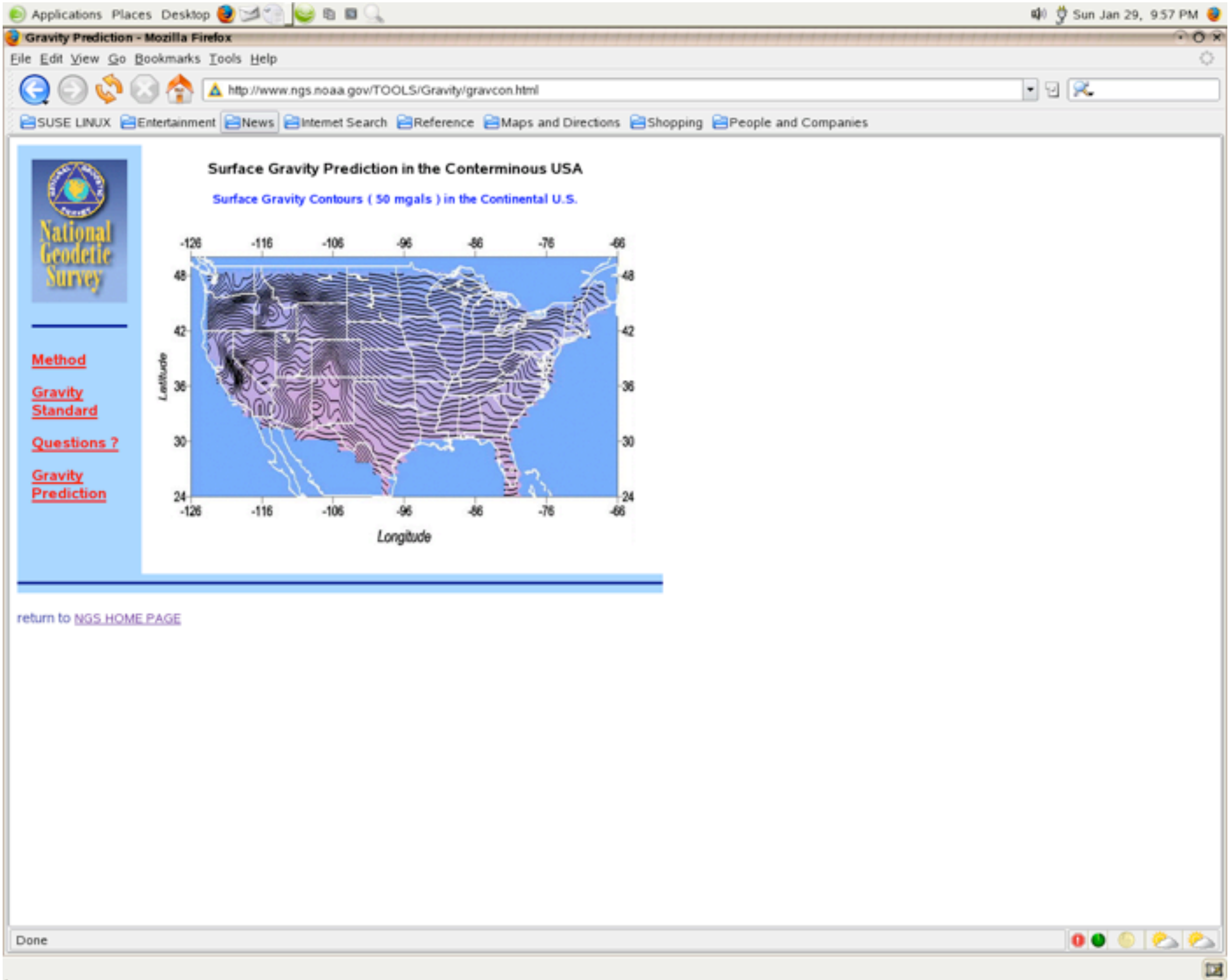


Figure 3

Wednesday, February 3, 2010


RELATIVE SIZE OF ENVIRONMENTAL CORRECTIONS
150
100
50
0
-50
100
150
Lunar/Solar Attraction
Solid Earth Response
Atmosphere
Ground Water
Ocean Loading
Polar Motion
Rotation Rate
+/-1.1 microGal instrument uncertainty


CHURCHILL, MANITOBA
g - 981752800 µGAL
32
28
24
20
16
12
8
4
0
-4
-8
-12
1980
1983
1985
1988
1991
1994
1996
1999
2002
2005
2007
2010
TIME (Yrs)
Gravity Values
+ 95% Error Bound
- 95% Error Bound
Trend -1.91 ± 0.19 µGal/Yr
2 cm
uplift
ICE-3G Theoretical (-1.11 µGal/yr)


Applications Places Desktop
Sun Jan 29, 9:57 PM
Gravity Prediction - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://www.ngs.noaa.gov/TOOLS/Gravity/gravcon.html
SUSE LINUX Entertainment News Internet Search Reference Maps and Directions Shopping People and Companies
National Geodetic Survey
Method
Gravity Standard
Questions ?
Gravity Prediction
Surface Gravity Prediction in the Conterminous USA
Surface Gravity Contours (50 mgals) in the Continental U.S.
-126 -116 -106 -96 -86 -76 -66
48 42 36 30 24
Latitude
Longitude
return to NGS HOME PAGE
Done

Applications Places Desktop Sun Jan 29, 10:12 PM

NGS SURFACE GRAVITY PREDICTION - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://www.ngs.noaa.gov/cgi-bin/grav_pdx.prl

SUSE LINUX Entertainment News Internet Search Reference Maps and Directions Shopping People and Companies

Surface Gravity Prediction

This page is maintained by Craig Larrimore

updated:06/22/05.09:19:05

Surface Gravity Prediction

Surface gravity is predicted by interpolation based on observed values. Observed gravity data in the National Geodetic Survey's Integrated Data Base are referenced to the International Gravity Standardization Net 1971, which is an absolute gravity datum.

ENTER: Latitude, Longitude and height above Mean Sea Level

The entry of mean sea level (topographic) height is NOT mandatory - the prediction of surface gravity value is still possible (frequently with diminished accuracy).

[may enter latitude and longitude in three formats:
1. degrees, minutes and seconds (xxx xx xx.xxx)
2. degrees and minutes (xxx xx.xxx)
3. degrees (xxx.xxxxx)
may enter height in meters or feet:
1. in meters: xxxx.xxx
2. in feet : xxxx.xxx FT (MUST include FT or ft for feet !)
Note: decimals can be keyed commensurate with the entry's precision, but are not required;
MUST include one or more blanks between entry fields]

ENTER Latitude :

ENTER Longitude: **(positive WEST)**

ENTER Sea level height:

When the site's sea level height is unknown DO NOT ENTER ZERO, but leave the entry field BLANK !

Let's go Clear

Be patient after clicking on "Let's go", data base access and computations may take a few seconds.

It is possible that the surface gravity prediction may not succeed; there could be numerous reasons for this, including position and height entry errors. In such case an error code is returned; questions concerning the gravity prediction process may be mailed to NGS

Done

The predicted gravity is given in units of 'milligals':

1 gal = 1 cm/sec^2 ('gal' in honor of Galileo)

1 kilogal = 1000 gal

1 milligal = 1/1000 gal

Questions concerning the gravity prediction process may be mailed to NGS

Latitude: 27 42 52.08857

Longitude: 097 19 44.31265

MSL Height: 5

Predicted gravity: 979129 +/- 2 milligals

NAVD 88 Gravity Computations

Use this program to compute NAVD 88 surface gravity as a function of latitude and longitude.

Gravity is computed by the method used to compute gravity for the NAVD 88 adjustment.
This is also the method used to compute the Modelled Gravity which shows on NGS data sheets.
Computations may be performed for a specific geographical location or for a file of input points.

The NAVD 88 gravity may differ from the measured gravity at a point,
or from the gravity value produced by the Surface Gravity tool in this toolkit by a few milligals.
This is because:

- The interpolation method used in computing NAVD 88 gravity may introduce some smoothing of measured values.
- NAVD 88 gravity is computed using a gravity model determined at the time of the NAVD 88 adjustment.
  New or revised values added to the NGS gravity data base since that time may affect the Surface Gravity computations but will have no effect on the NAVD 88 gravity.

Compute NAVD 88 gravity for a specific location:

Enter North Latitude and West Longitude below.
All values must be entered as integers (no decimals).
The NAVD 88 gravity model is valid only within the coterminous United States.

	Degrees	Minutes	Seconds(integer only)
Latitude	27	42	52
Longitude	097	19	44

Compute NAVD 88 Gravity for a Single Location | Clear Form

Output from NAVD Gravity Computations

NGS program grav_info (formerly GETGRAV)   version: 2.3   date: 01/04/25

latitude	longitude	gravity(gals)	std. dev.(mgal)
274252	0971944	979.1280	2.7

NGS HOME PAGE

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latitude	longitude	gravity(gals)	std. dev.(mgal)
274252	0971944	979.1280	2.7

NGS HOME PAGE

Which model to use?

- NAVD88 - Modeled Gravity uses a model developed for the NAVD88 adjustment rather than current gravity values.

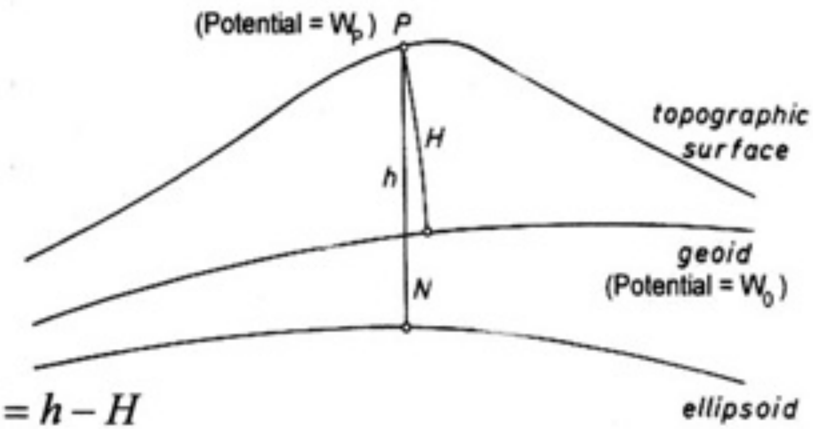
Review of Height Systems

- <u>Helmert Orthometric</u>
- NAVD 88

$$H = \frac{C}{\bar{g}} = \frac{C}{g + 0.0424H}$$

$$\bar{g} = g - \left(\frac{1}{2}\frac{\partial \gamma}{\partial h} + 3\pi G\rho\right)H$$

- local gravity field ($\bar{g}$)
- single datum point
- follows MSL



$$N = h - H$$

$$H_{dyn} = \frac{C}{\gamma_0} = \frac{W_0 - W_P}{\gamma_0}$$

$$H = \frac{C}{\bar{g}} = \frac{W_0 - W_P}{\bar{g}}$$

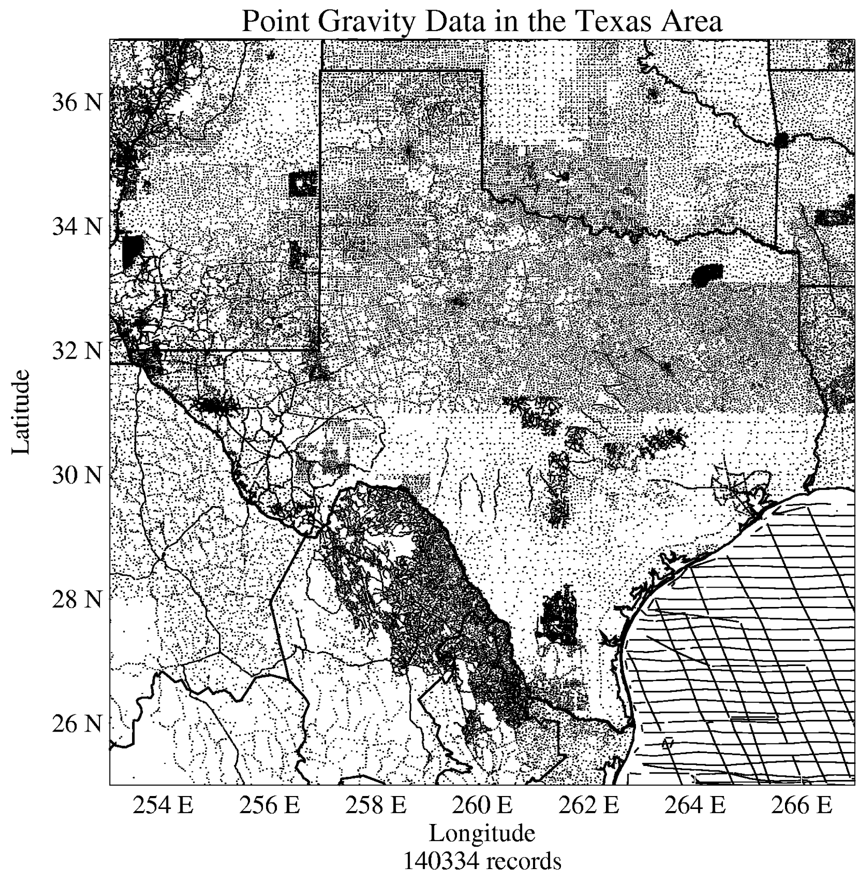
$$H = \frac{C}{g + 0.0424H} = \frac{H_{dyn} \cdot \gamma_0}{g + 0.0424H}$$

Units: gravity · [gals]
height · [km]

HTDP from NGS web

Earth's Gravity Field from Space

- Satellite data was used for global models
  - Only useful at wavelengths of 700 km or longer
- Lower wavelength data from terrestrial or marine gravity of varying vintage, quality and geographic coverage



Gravity

- Static gravity field
  - Based on long-term average within Earth system
- Temporally changing component
  - Motion of water and air
  - Time scale ranges from hours to decades.
- Mean and time variable gravity field affect the motion of all Earth space vehicles.

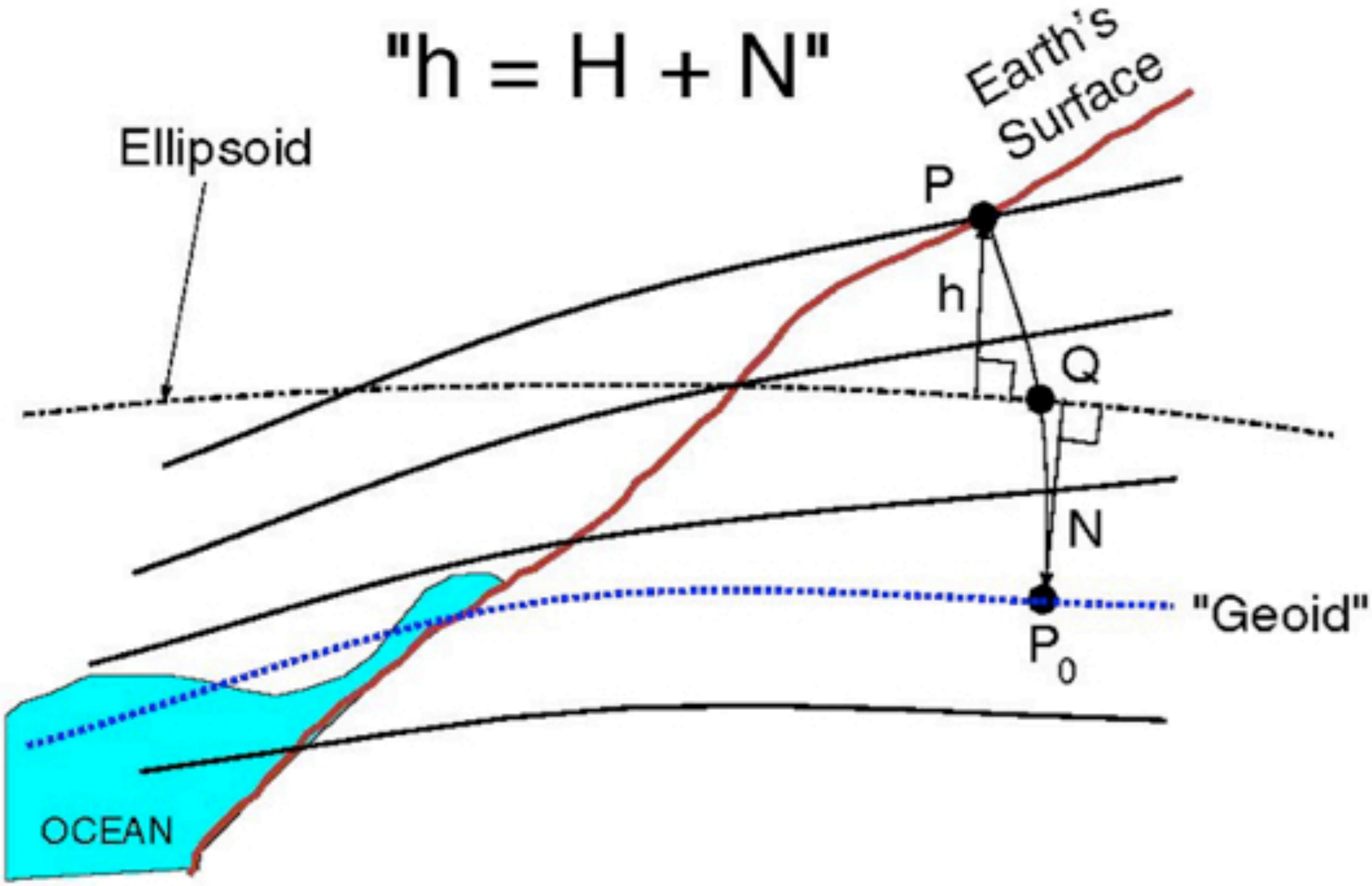
Geoid

ζ = Mean Ocean Dynamic Topography

Even after time-averaging, Local Mean Sea Level does not correspond to a level surface.

ζ is induced by permanent ocean circulation patterns, salinity, temperature and wind set-up, which vary geographically.

- The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level.

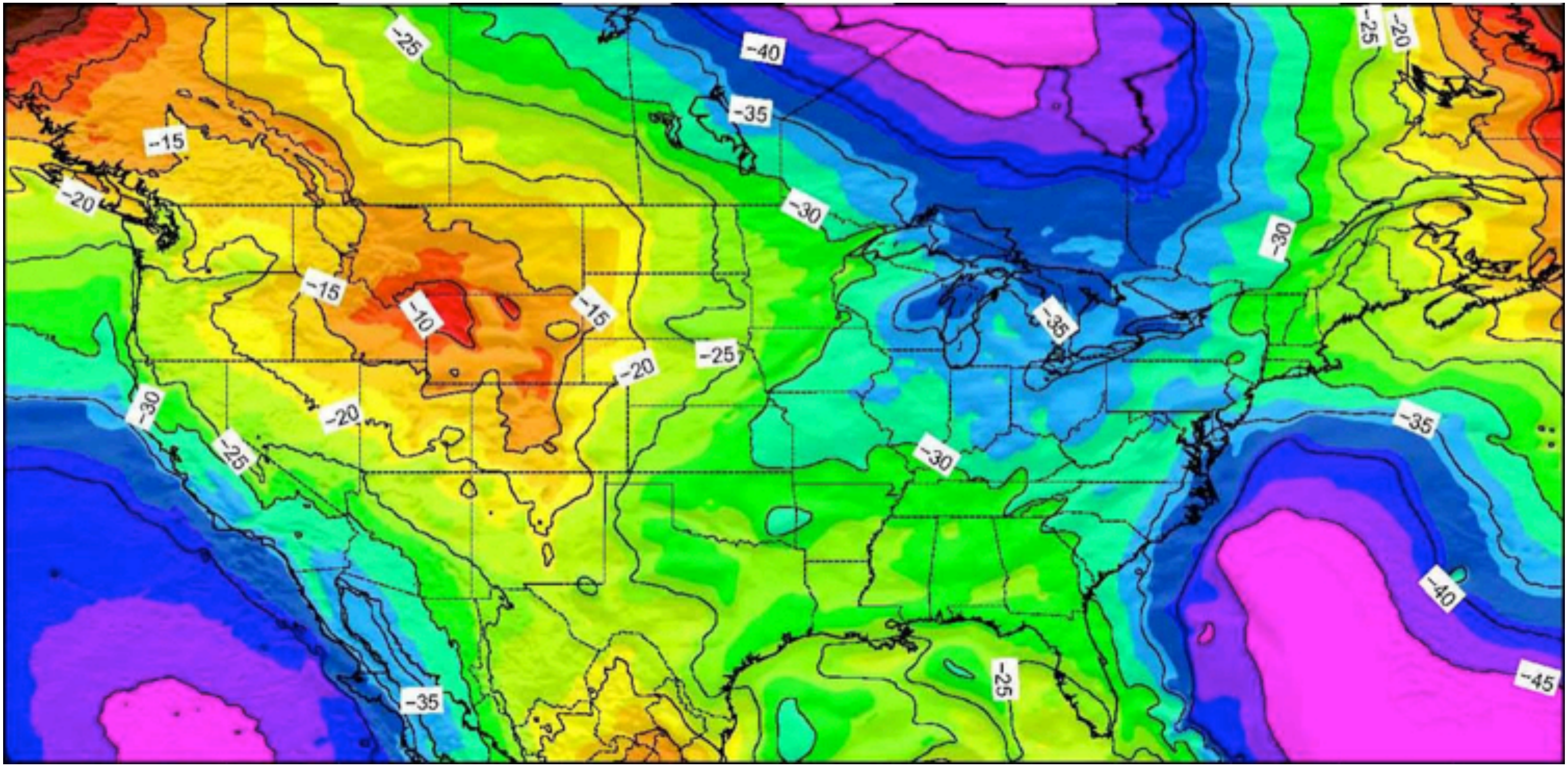


h (Ellipsoid Height) = Distance along ellipsoid normal (Q to P)

N (Geoid Height) = Distance along ellipsoid normal (Q to P_0)

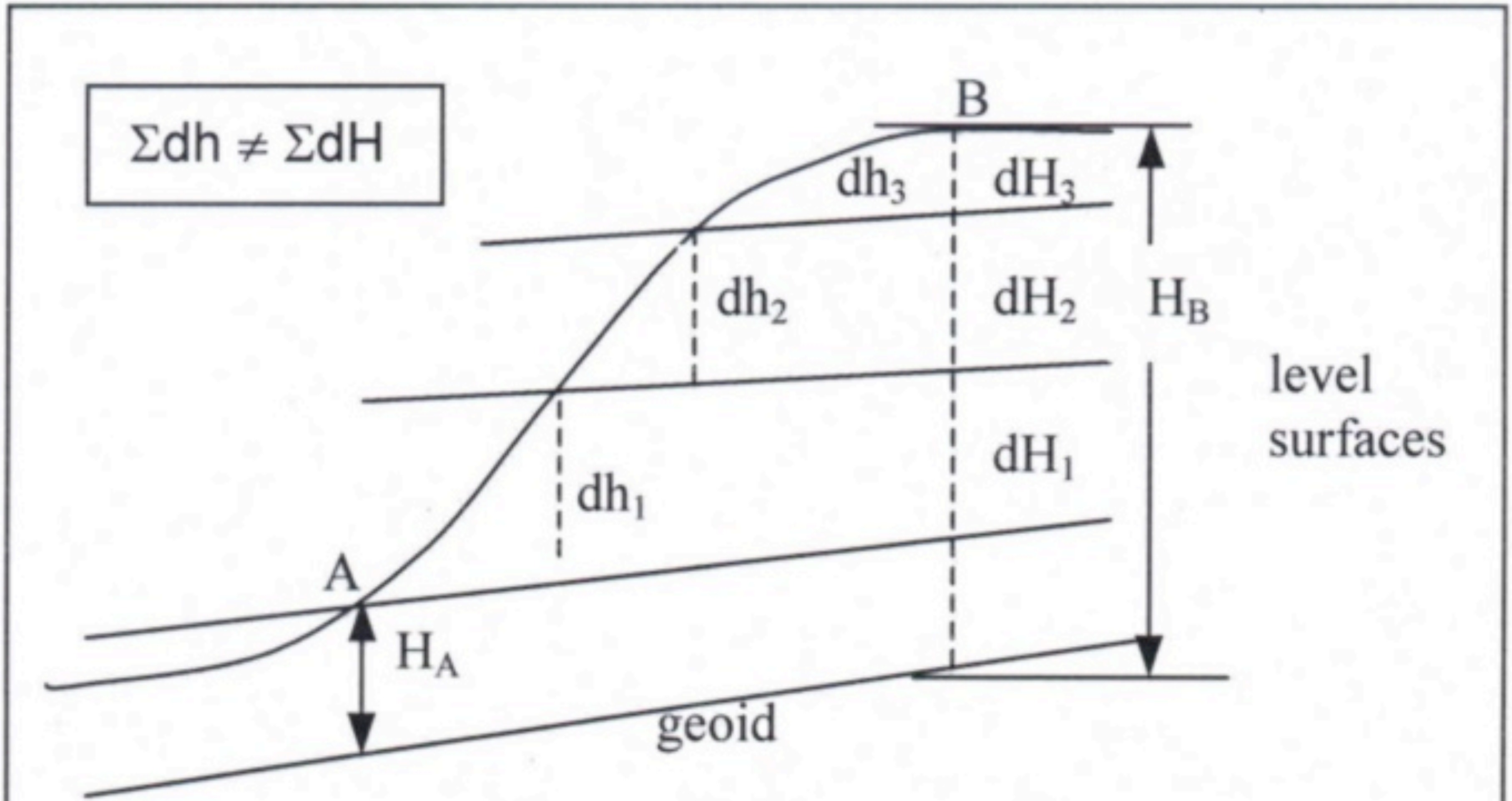
H (Orthometric Height) = Distance along Plumb line (P_0 to P)

GEOID 2009



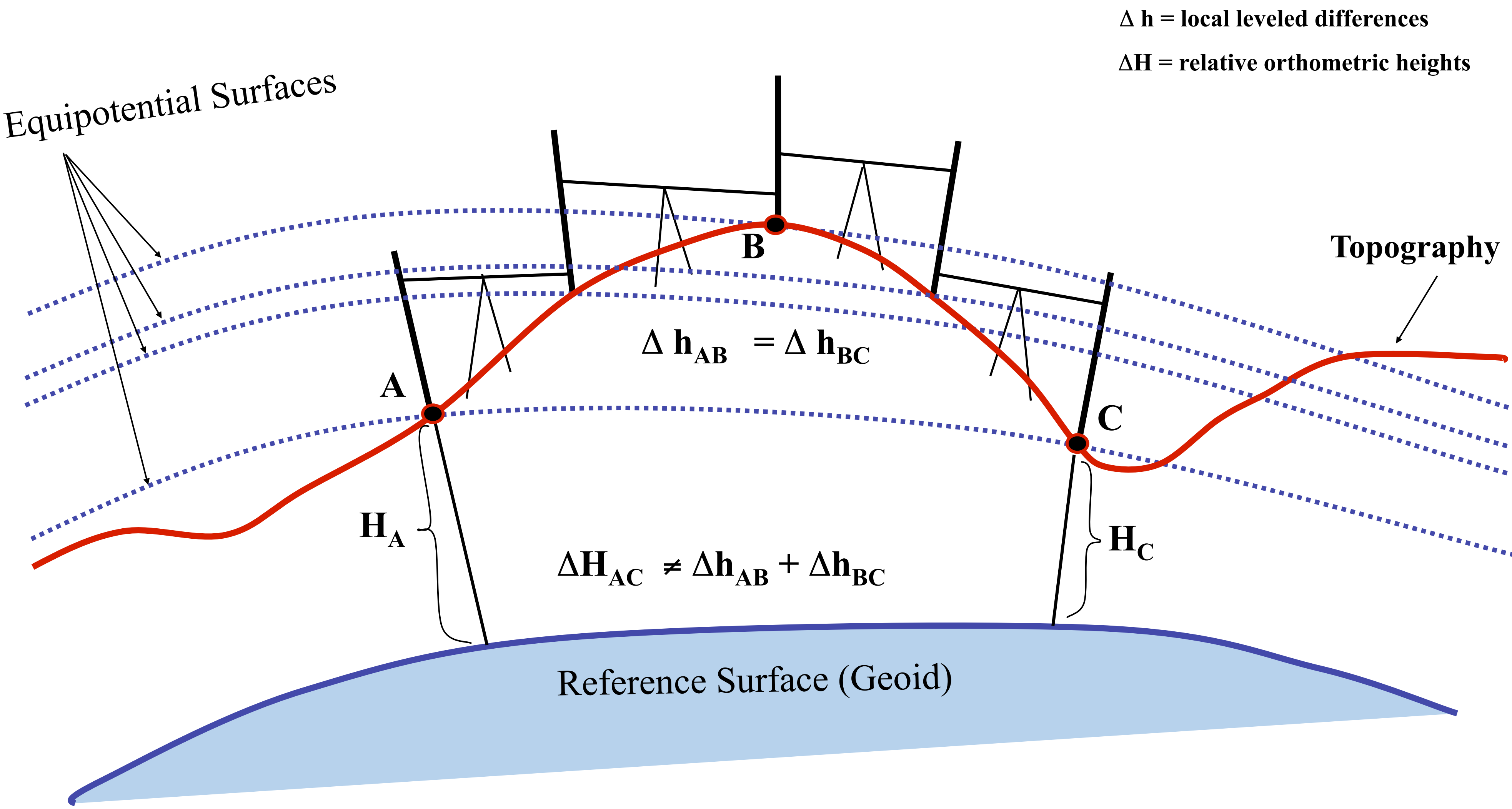
Leveling Issues

- Height
  - The distance measured along a perpendicular between a point and a reference surface.
- Raw leveled heights
  - Non-unique. Depending on the path taken a different height will be determined for the same point. **They have NO *physical* relevance.**



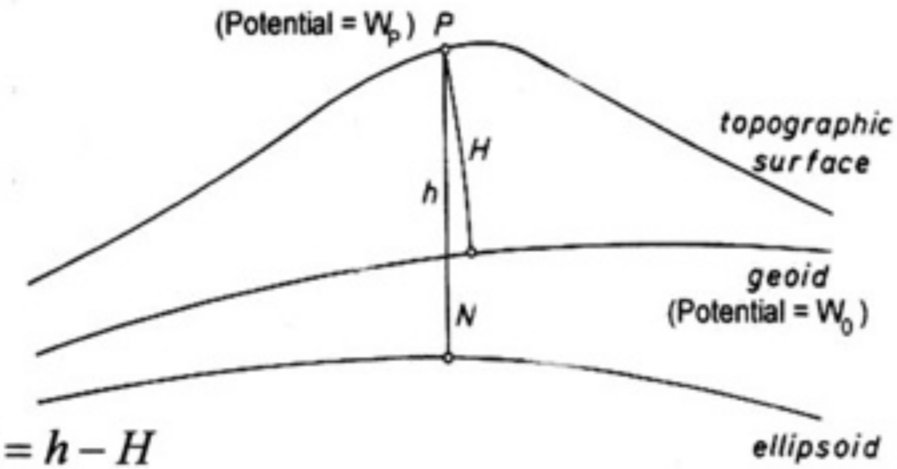
Leveled Height (dh) vs. Orthometric Height (dH)

Leveled Height vs. Orthometric Height



Observed difference in orthometric height, ΔH, depends on the leveling route.

```
================================================================================================

Adjusted Geopotential Numbers/Elevations by Line


Line/Part: L26356/5           SSN+:  mark floated,  SSN*:  mark constrained,  SSN#:  mark floated & constrained
Mark ID   SSN     PID    Designation                                   Geopotential   Elevation   Codes

     0    1377*  HU0596  W 105                                               2.5267      2.5783
     1    1376*  HU0597  MOORES AZ MK                                        2.3772      2.4257
     2    1378*  AI7161  Y 107 RESET                                         2.2908      2.3376
     3    1379   HU0600  X 105                                               2.6299      2.6836
     4    1380*  AJ8000  TULLS                                               2.1135      2.1567

     5    1381*  HU0602  Z 105                                               2.7154      2.7709

================================================================================================
```



$$N = h - H$$

$$H_{dyn} = \frac{C}{\gamma_0} = \frac{W_0 - W_P}{\gamma_0} \qquad H = \frac{C}{g + 0.0424H} = \frac{H_{dyn} \cdot \gamma_0}{g + 0.0424H}$$

$$H = \frac{C}{\bar{g}} = \frac{W_0 - W_P}{\bar{g}}$$

Units: gravity : [gals]
height : [km]

HTDP from NGS web

Dynamic Heights

- Takes the geopotential number at a point and divides it by a constant gravity value.
- The constant value used in the US is the normal gravity value at 45 degrees N latitude
  - 980.6199 gals

CC area Dynamic Heights

```
1         National Geodetic Survey,   Retrieval Date = JANUARY 31, 2007
 AC8464 ***********************************************************************
 AC8464  TIDAL BM     -  This is a Tidal Bench Mark.
 AC8464  DESIGNATION -  877 5792 A TIDAL
 AC8464  PID         -  AC8464
 AC8464  STATE/COUNTY-  TX/NUECES
 AC8464  USGS QUAD   -  CRANE ISLANDS NW (1975)
 AC8464
 AC8464                         *CURRENT SURVEY CONTROL
 AC8464  ___________________________________________________________________
 AC8464* NAD 83(1986)-  27 38 05.     (N)    097 14 15.     (W)     SCALED
 AC8464* NAVD 88     -         0.840  (meters)       2.76   (feet)  ADJUSTED
 AC8464  ___________________________________________________________________
 AC8464  GEOID HEIGHT-        -25.91  (meters)                      GEOID03
 AC8464  DYNAMIC HT  -          0.839 (meters)       2.75   (feet)  COMP
 AC8464  MODELED GRAV-    979,127.0   (mgal)                        NAVD 88
 AC8464
 AC8464  VERT ORDER  -  FIRST     CLASS II
```

NAVD 88 and dynamic heights differ by only 1 mm at this station.

Dynamic Heights

```
DATABASE = Sybase ,PROGRAM = datasheet, VERSION = 7.42
1        National Geodetic Survey,   Retrieval Date = JANUARY 31, 2007
 AC5717 ***************************************************************************
 AC5717  DESIGNATION -  7850
 AC5717  PID         -  AC5717
 AC5717  STATE/COUNTY-  TX/JEFF DAVIS
 AC5717  USGS QUAD   -  MOUNT LOCKE (1978)
 AC5717
 AC5717                        *CURRENT SURVEY CONTROL
 AC5717  ____________________________________________________________________
 AC5717* NAD 83(1993)-  30 40 49.77247(N)    104 00 54.30121(W)     ADJUSTED
 AC5717* NAVD 88     -      2026.545  (meters)    6648.76   (feet)  ADJUSTED
 AC5717  ____________________________________________________________________
 AC5717  X           -  -1,330,007.642 (meters)                    COMP
 AC5717  Y           -  -5,328,393.026 (meters)                    COMP
 AC5717  Z           -   3,236,502.804 (meters)                    COMP
 AC5717  LAPLACE CORR-         -0.25   (seconds)                   DEFLEC99
 AC5717  ELLIP HEIGHT-       2005.36   (meters)        (10/23/00)  GPS OBS
 AC5717  GEOID HEIGHT-        -21.19   (meters)                    GEOID03
 AC5717  DYNAMIC HT  -       2023.109 (meters)    6637.48  (feet)  COMP
 AC5717  MODELED GRAV-     978,871.0   (mgal)                      NAVD 88
 AC5717
 AC5717  HORZ ORDER  -  B
 AC5717  VERT ORDER  -  FIRST     CLASS II
 AC5717  ELLP ORDER  -  FOURTH    CLASS II
```

NAVD 88 = 2026.545 m

DYN Hght= 2023.109

Difference = 3.436 m

DYNAMIC_HT

This page is maintained by NGS Software Requests

This utility computes a dynamic height
based on the input NAVD 88 orthometric height and gravity value
For more information about dynamic heights
see file dynamic_ht.doc

Enter a surface gravity value in units of mgal
or a latitude and longitude to have the program
automatically interpolate a gravity value.

The latitude and longitude on the NAD 83 datum has the following permissable formats:

- degrees and decimals (xx.xxxx)
- degrees, minutes and decimals (xx xx.xxxx)
- degrees, minutes, seconds and decimals (xx xx xx.xxxx)

The input elevation should be in meters and decimals.

Surface Gravity: [ ] -OR- Latitude: 30 40 49.8
Longitude: 104 00 53.9

NADV88 Helmert Orthometric Height: 2026.545

Press 'Submit' to compute a dynamic height for the above input.

Submit | Clear | Sample1 | Sample2 | Sample3 | Sample4

Return to GEODETIC TOOLKIT PAGE   Return to NGS HOME PAGE

Dynamic Height Problems

- Dynamic height corrections applied to spirit-leveled height differences can be very large (several meters) if the chosen gravity value is not representative for the region of operation.

Orthometric correction

- Occurs because equipotential surfaces are not parallel.
- In general, not parallel in a N-S direction but they are parallel in an E-W direction.
- It is computed as a function of mean orthometric height and latitude of section.

Leveled v Ortho. Height Diffs

- Due to non-parallelism of level surfaces the differences between published NAVD 88 points do not correspond to the leveled height difference.
- Therefore the subtraction of the published NAVD 88 heights on the NGS datasheets will NOT agree with the leveled difference.
- This is problem mostly in high elevations.

NGS LVL_DH Program

This page is maintained by NGS Software Requests

Compute the expected leveled height differences between two NAVD 88 bench marks

---

This utility uses NGS program LVL_DH
to compute height differences
between two NAVD 88 bench marks
by one of the two methods below.

For more information about the computation see file lvl_dh.doc

---

1. RETRIEVE BY VALUES...

Clear or overwrite the Orthometric Height and Gravity Value
for the two MARKS below,
then click Submit to compute results.

	MARK #1	MARK #2
Ortho. Ht. =	500.000	525.333
Gravity =	978222.000	978225.444

Submit Clear Sample

2. RETRIEVE BY PIDs...

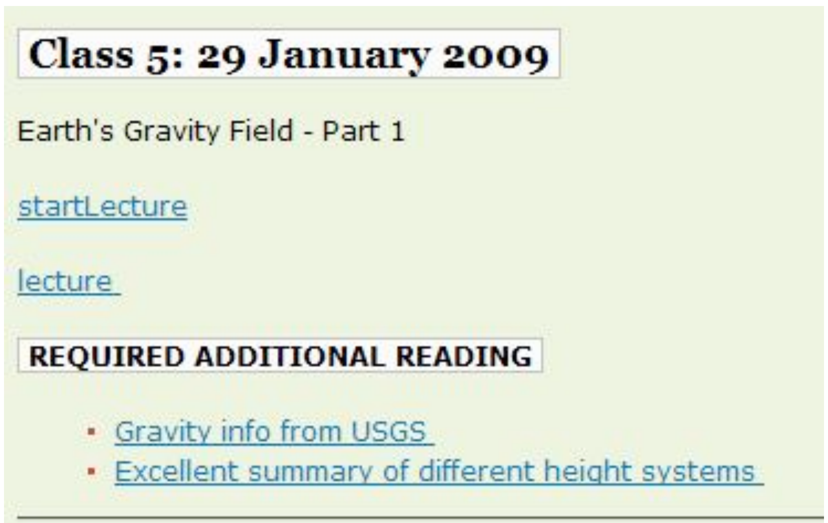
An example from Colorado

- The difference between published NAVD 88 heights is 402.156 m.
- The leveled difference is 402.085 m.

```
                 Level Height Difference Computation
                          LVL_DH Program
                           Version 2.1

===============================================================================

                         Computation #:     1
        HEIGHT 1     GRAV 1        HEIGHT 2     GRAV 2      LEVEL DIFF.
        (meters)     (mgal)        (meters)     (mgal)      (meters)

        2659.349     979133.2      3061.505     979074.9    402.085

===============================================================================
```

Reminder

- You are responsible for the material listed as REQUIRED ADDITIONAL READING in the Class 5 section of the web page.



Class 5: 29 January 2009

Earth's Gravity Field - Part 1

startLecture

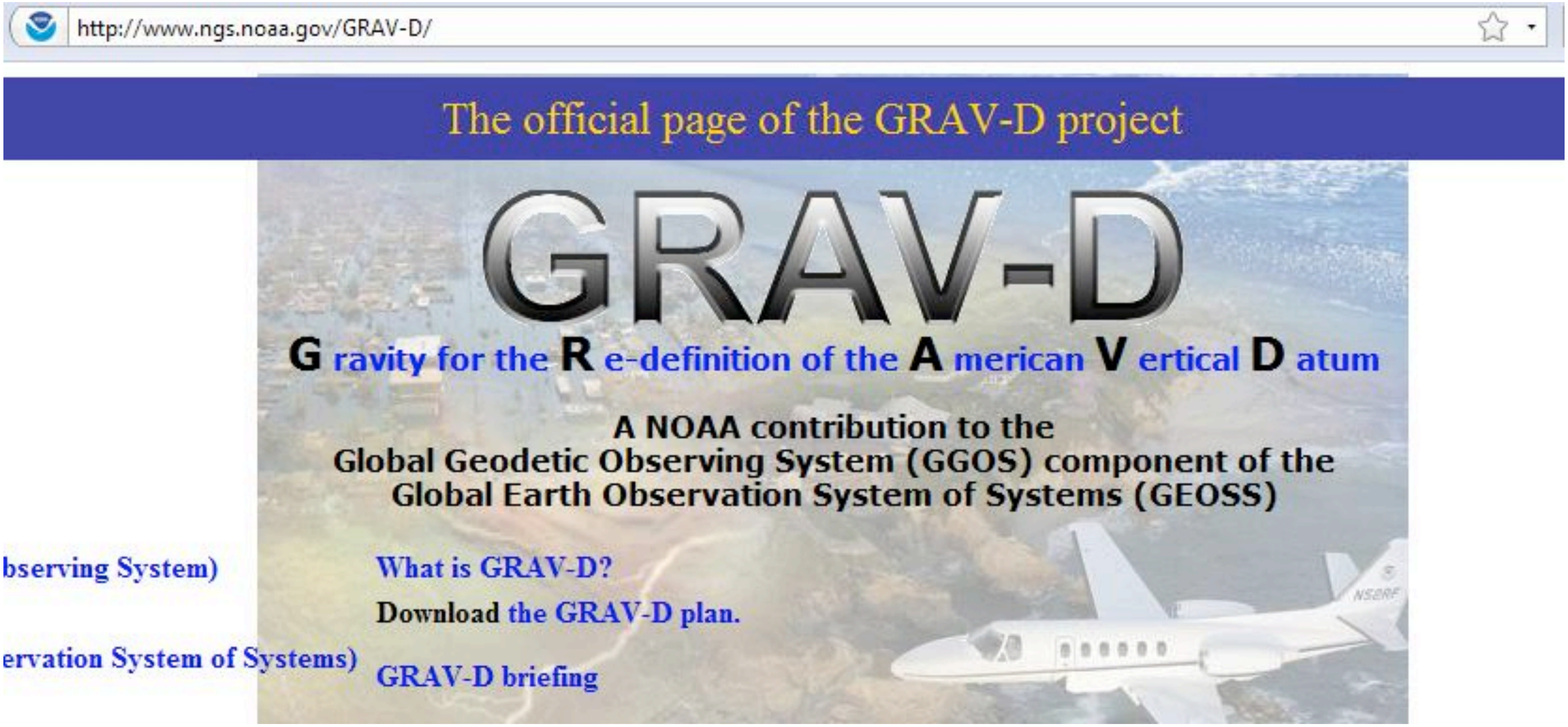
lecture

REQUIRED ADDITIONAL READING

- Gravity info from USGS
- Excellent summary of different height systems

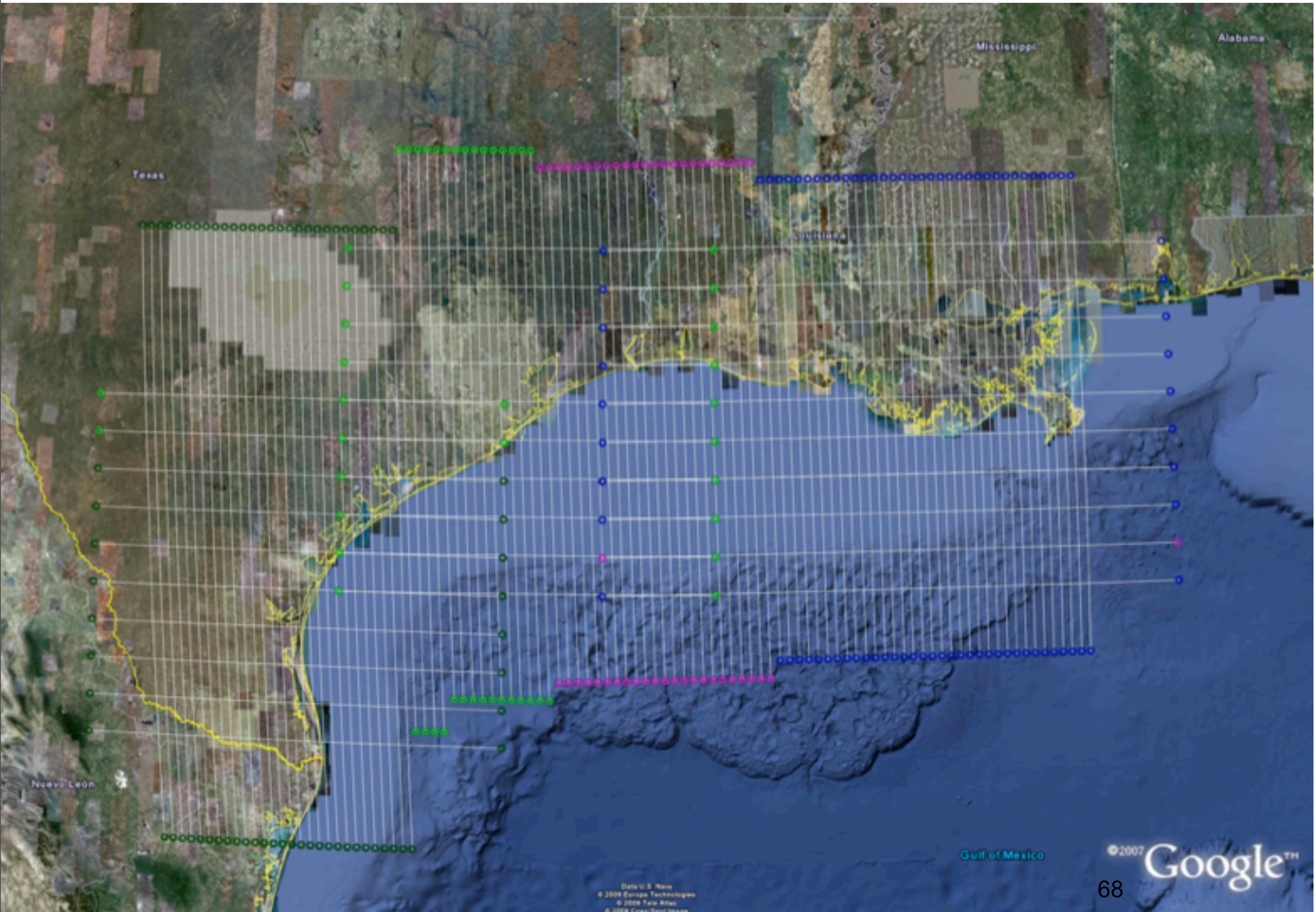

MADE IN
AUSTIN, TEXAS
U.S.A.
10.7
2005/01/24

http://www.ngs.noaa.gov/GRAD-D




CONTROL MODULE
MICRO
LACOSTE


TAGS
S-137
21/ 1/2008 7: 4:26
-0.0
CC (cu)
30.1
TC (cu)
7184.0
ST (cu)
7230.6
GRAVITY (cu)
7197.3
QC GRAV(mGal)
0.456
DCAM (Volts)
4.87
49.7
19.5
Speed
522.00
Eotvos
-0.03
Heading
Altitude
10850.65
Turn Tracking
Move to
7645
PLOT WIDTH IN HOURS
0.2
CLEAR CHART


Texas
Mississippi
Alabama
Louisiana
Nuevo León
Gulf of Mexico
©2007 Google™

Gravity field and steady-state Ocean Circulation Explorer

Description
The GOCE gradiometer contains three pairs of proof masses positioned at the outer ends of three 50 cm long orthogonal arms. Because of their different position in the gravitational field they all experience the gravitational acceleration of the Earth slightly differently. The three axes of the gradiometer allow the simultaneous measurement of six independent but complementary components of the gravity field.

Facts and figures

Full name: Gravity field and steady-state Ocean Circulation Explorer

Launch: March 2009

Launcher: Rockot (with Breeze-KM upper stage) by Eurockot Launch Services GmbH

Launch site: Plesetsk Cosmodrome, Russia

Mission control: European Space Operations Centre (ESOC), Darmstadt, Germany

Number of instruments: 3

Nominal life: 20 months

Mission cost: €340 million (including launcher and operations)

Orbit: about 260 km altitude, polar, Sun-synchronous

Mass: 1100 kg

Size: 5.3 m long, about 1 m body diameter

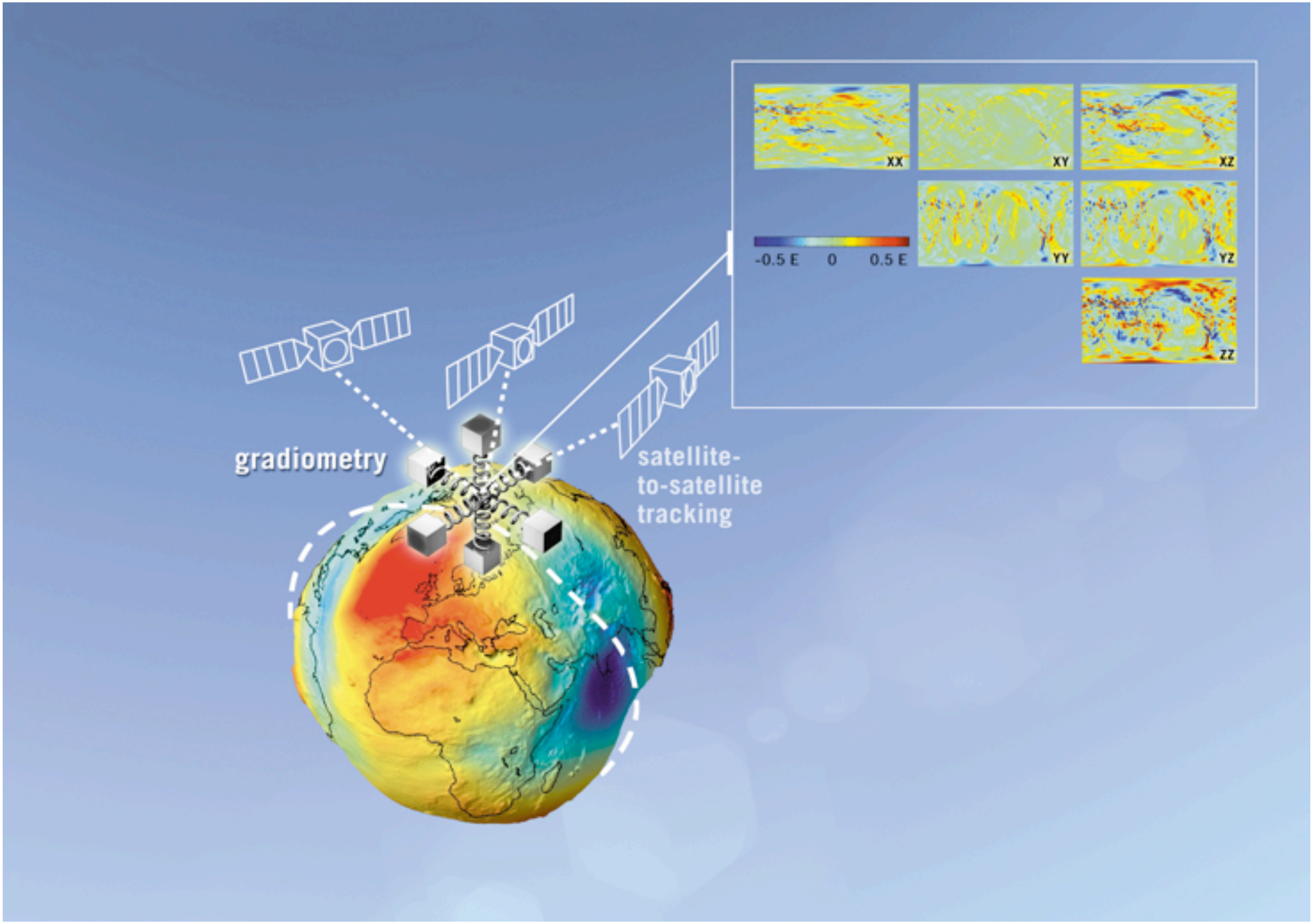
Propulsion tank: 40 kg of xenon

Geoid accuracy: 1 - 2 cm vertically with 100 km spatial resolution

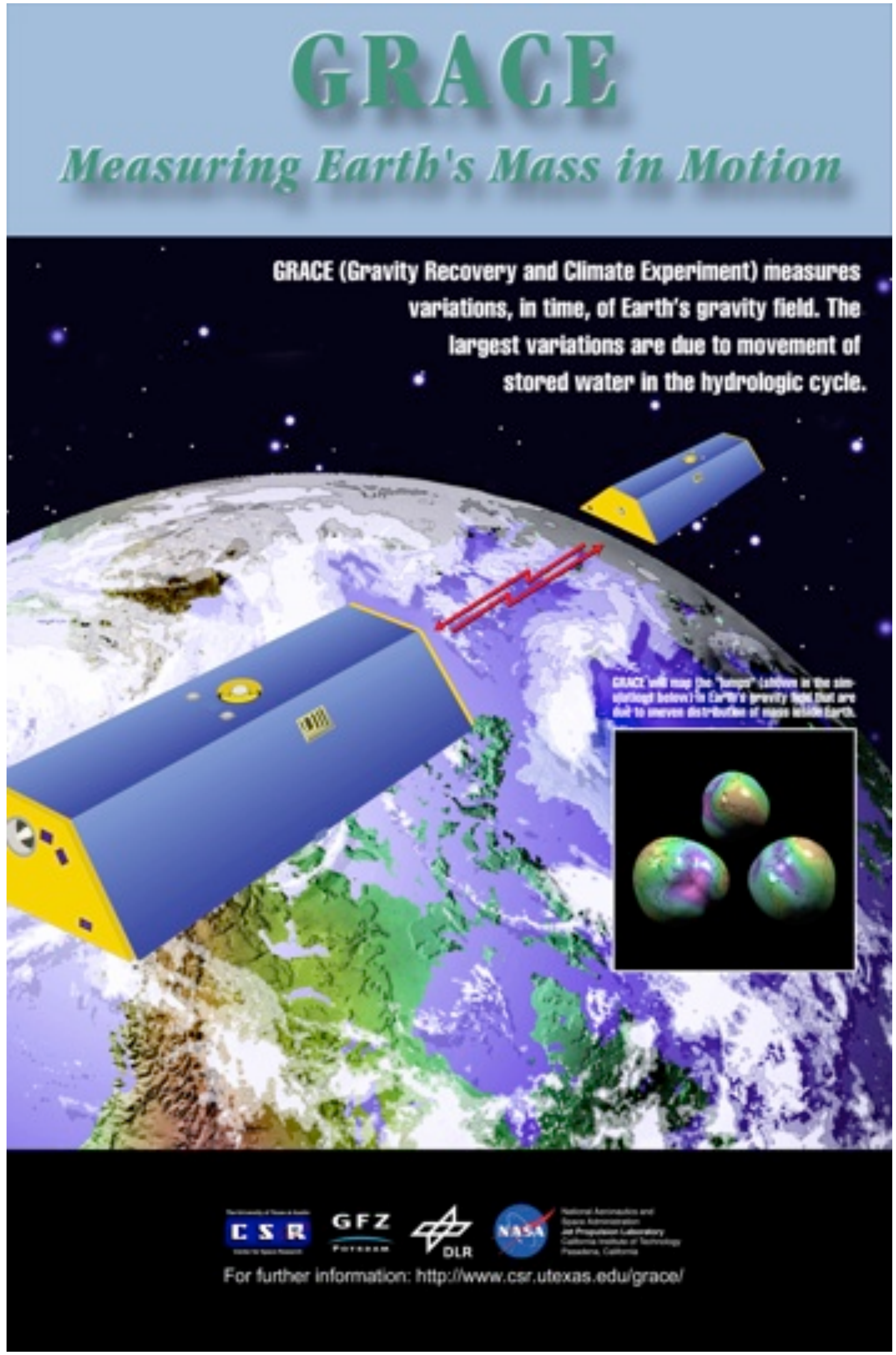
Gravitational acceleration at Earth's surface is about 9.8 m/s^2, varying from a minimum of 9.788 m/s^2 at the equator to a maximum of 9.838 m/s^2 at the poles.

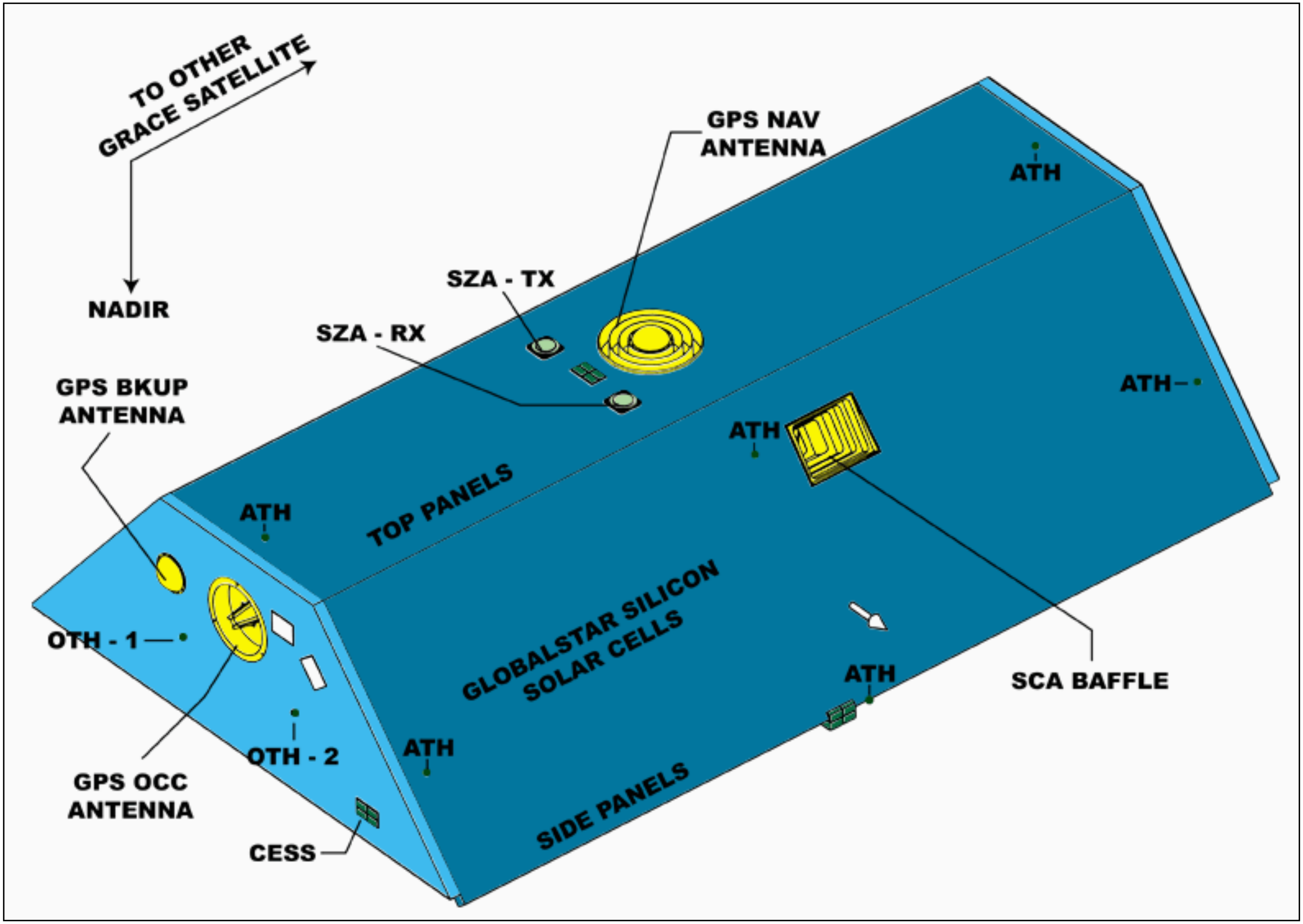
The six accelerometers (three pairs in three orthogonal directions) are some 100 times more sensitive than any previously flown in space.

Planning and construction of the GOCE spacecraft involved 45 European companies led by Thales Alenia Space.

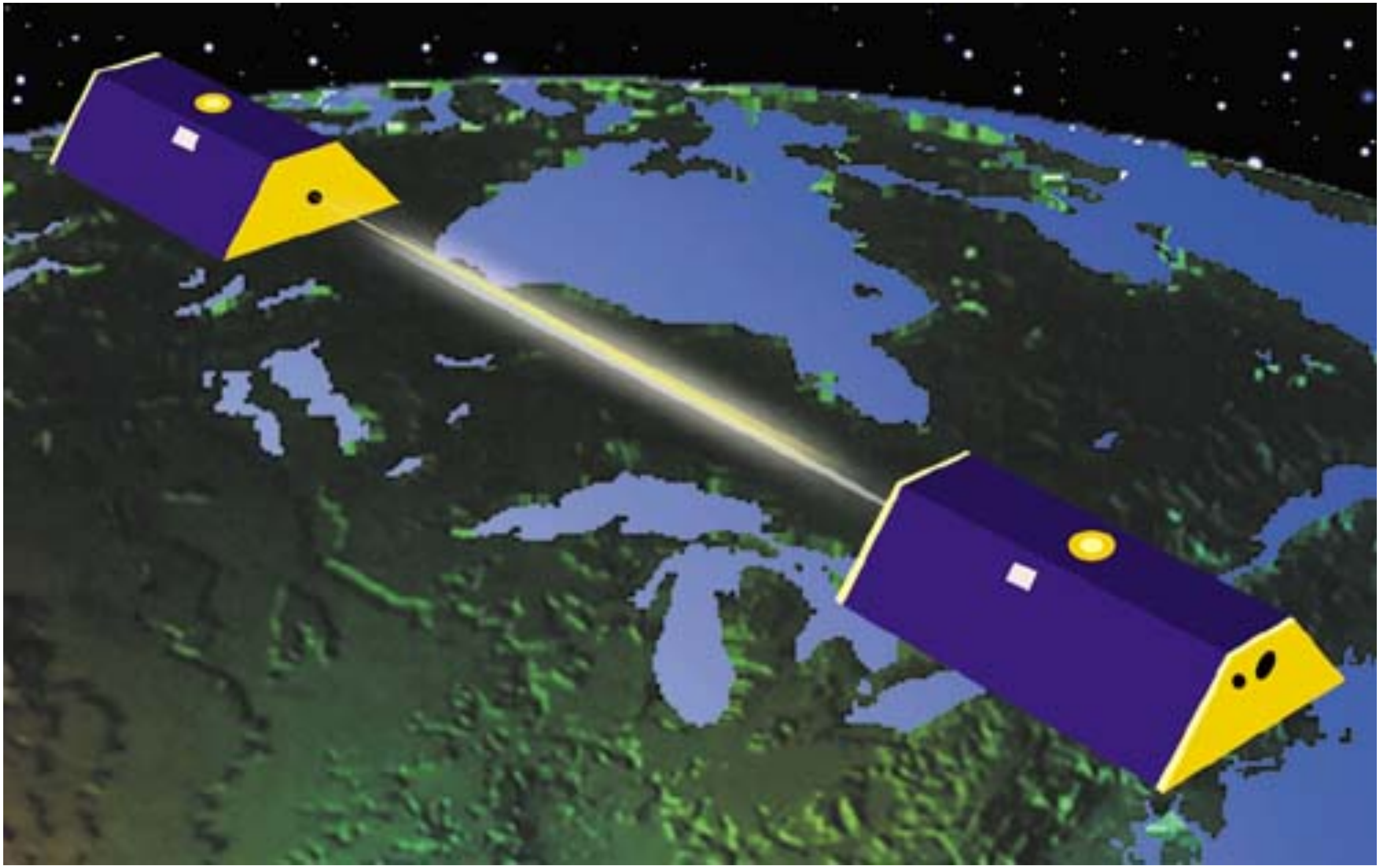

XX
XY
XZ
YY
YZ
ZZ
-0.5 E
0
0.5 E
gradiometry
satellite-
to-satellite
tracking

Gravity
Recovery
And
Climate
Experiment




TO OTHER
GRACE SATELLITE
NADIR
GPS NAV
ANTENNA
ATH
SZA - TX
SZA - RX
GPS BKUP
ANTENNA
ATH
ATH
ATH
TOP PANELS
GLOBALSTAR SILICON
SOLAR CELLS
OTH - 1
ATH
SCA BAFFLE
OTH - 2
ATH
GPS OCC
ANTENNA
SIDE PANELS
CESS

GRACE

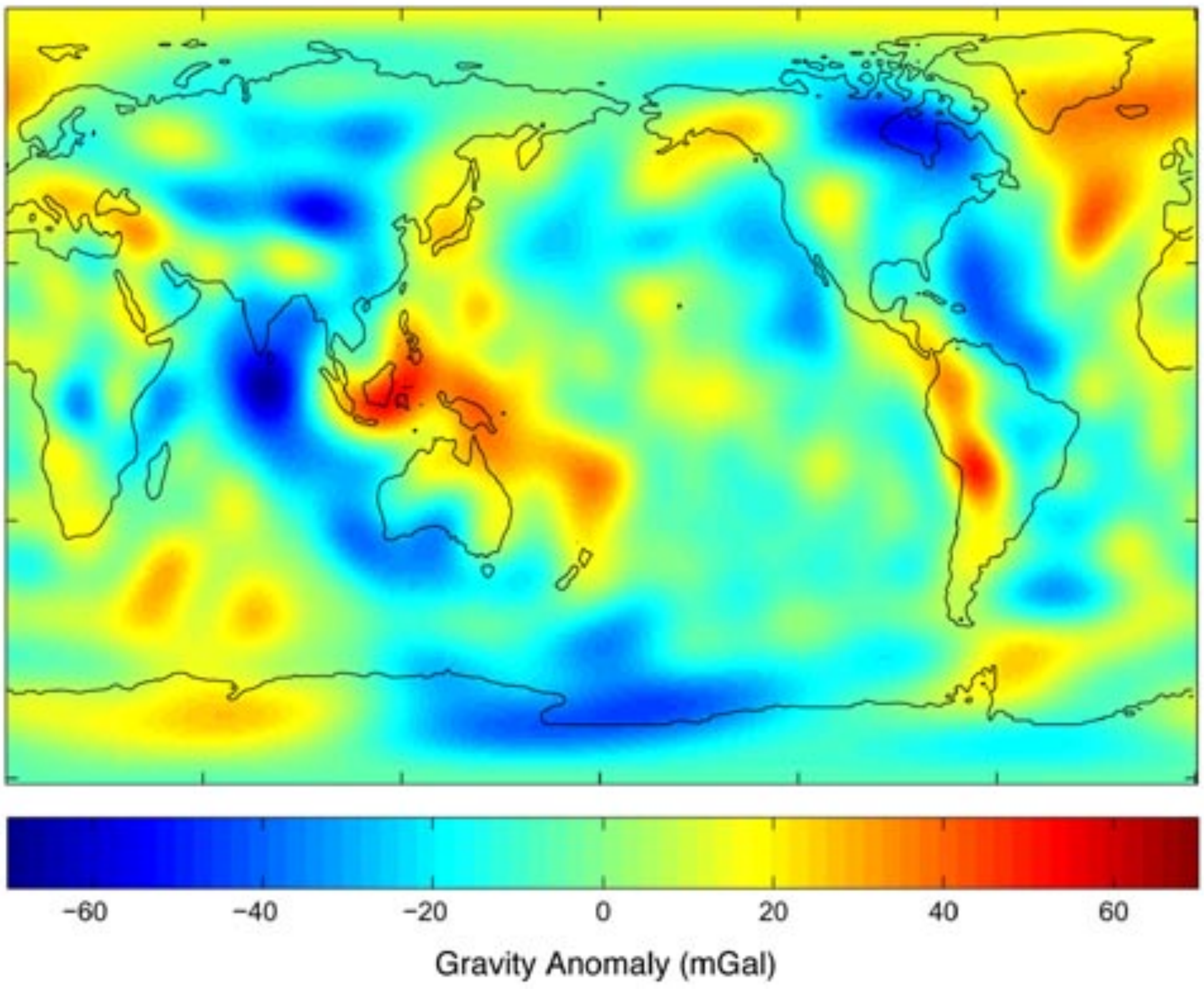


How does GRACE work?

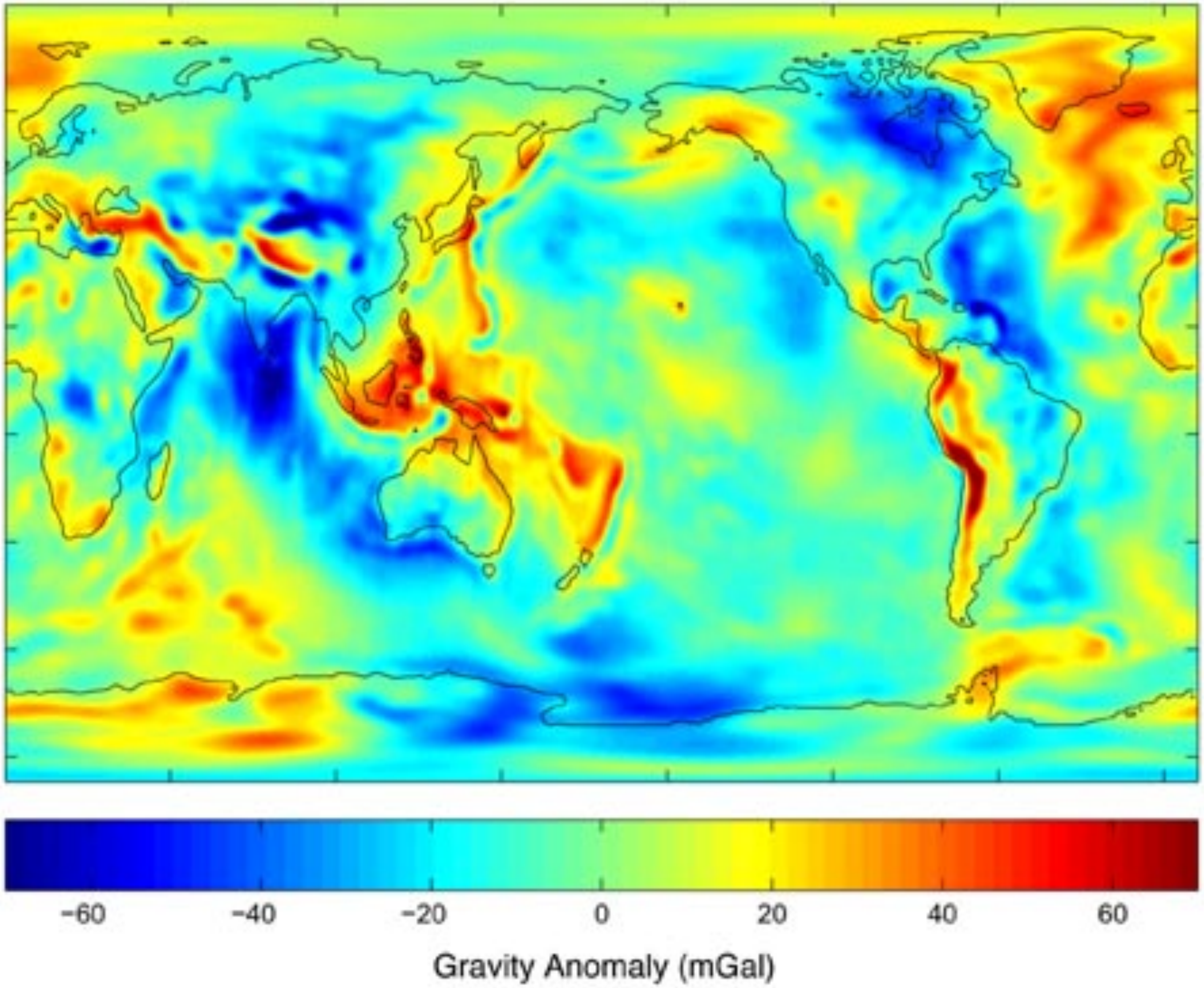
- Motion of two satellites differ because they are at different positions in space.
- When the lead SV approaches a higher gravity mass it accelerates as it moves beyond it decelerates.
- Distance changes between SVs is measured precisely.


http://www.csr.utexas.edu/grace/ground/globe.html
GRACE
Gravity Recovery and Climate Experiment
CSR
GFZ
GRACE 5th ANNIVERSARY 2002 - 2007
HOME
SCIENCE
OPERATIONS
MISSION
FLIGHT SYSTEMS
CSR
GAMES
EDUCATION
PUBLICATIONS
GALLERY
SEARCH
search
Current Orbit Data
GRACE Launch
GRACE Newsletter
GRACE Partners
Mission Overview
GRACE Ground Track
Grace1-To-Grace2 AER
Time (UTCG): 23 Apr 2007 12:48:03.00
Azimuth (deg): 0.214
Elevation (deg): -1.024
Range (km): 222.732810
Grace1 Classical Orbit Elements
Semi-major Axis (km): 6849.706754
Eccentricity: 0.000775
Inclination (deg): 89.048
RAAN (deg): 108.414
Arg of Perigee (deg): 356.373
True Anomaly (deg): 14.917
Mean Anomaly (deg): 14.894
Grace1 Solar AER
Time (UTCG): 23 Apr 2007 12:48:03.00
Azimuth (deg): 279.234
Elevation (deg): 14.042
Range (km): 150410625.999258
Grace1 ECF LLR Position
Time (UTCG): 23 Apr 2007 12:48:03.00
Grace1
Weilheim
23 Apr 2007 12:48:03.00
Satellite Tool Kit
File Edit Properties Tools Window Help
STK
UTOPIA
THE UNIVERSITY OF TEXAS AT AUSTIN
| HOME | SCIENCE | OPERATIONS | MISSION | FLIGHT SYSTEMS | CSR |
| GAMES | EDUCATION | PUBLICATIONS | GALLERY | SEARCH |
The GRACE mission is jointly implemented by NASA and DLR under the NASA Earth System Science Pathfinder Program.
Last Modified: Mon Apr 23, 2007
CSR/TSGC Team Web

Geoid Model from Earth Orbiting Space Vehicles (pre-GRACE)



GRACE 111 days of data



GRACE 363 days of data