NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Office of GEOINT Sciences

GRAVITY STATION DATA FORMAT

&

ANOMALY COMPUTATIONS

1 Oct 2008

DEFINITIONS AND EXPLANATIONS

1. Observed (or measured) Gravity (g) is the value of gravity at the station location. All values have been adjusted to the International Gravity Standardization Net of 1971.

2. Theoretical (Normal) Gravity (γ) is the reference gravity value obtained from the gravity field of the World Geodetic System (WGS 84) reference ellipsoid of revolution. It is given in closed form by:

$$\gamma = (978032.53359) \times \frac{(1+0.00193185265241\sin^2\phi)}{(1-0.00669437999014\sin^2\phi)^{1/2}} \text{ mgal} \qquad (1)$$

where ϕ equals geodetic latitude. In analytical form, equation (1) is given by

$$\gamma = \gamma_e \frac{(1+k\sin^2\phi)}{(1-e^2\sin^2\phi)^{1/2}} \qquad (1a)\ **$$

3. Atmospheric Gravity Correction (δg_A) is a correction that is added to observed gravity. It is necessary because the WGS 84 earth's gravitational constant includes the mass of the atmosphere. It is given by

$$\delta g_A = 0.87e^{-0.116\left[(h/1000)^{1.047}\right]} \text{ mgal for } h \geq 0 \qquad (2)$$

$$\delta g_A = 0.87 \text{ mgal for } h < 0$$

where h is the elevation with respect to sea level (SL).

4. Vertical Gradient of Normal Gravity ($\partial\gamma/\partial h$) is the rate of change of theoretical gravity in a vertical direction at the ellipsoidal surface. It is given by

$$\frac{\partial\gamma}{\partial h} = -2\frac{\gamma}{a}(1 + f + m - 2f(\sin^2\phi)). \qquad (3)^1$$

There is also a second order term which can be appreciable at high elevations. An approximation of the second order term is

$$\frac{\partial^2\gamma}{\partial h^2} = 6\frac{\gamma}{a^2} \qquad (4)^2$$

[1,2] reference: Heiskanen, W. & Moritz, H., Physical Geodesy, 1967, pp. 78, 79

** **NOTATION FOR EQUATION (1a)**

k = constant = $\frac{b\gamma_p}{a\gamma_e} - 1$

a = semimajor axis (WGS 84 Ellipsoid)

b = semiminor axis (WGS 84 Ellipsoid)

γ_p = normal gravity at the poles (WGS 84 EGM 96 Earth Gravity Model)

γ_e = normal gravity at the equator (WGS 84 EGM 96 Earth Gravity Model)

ϕ = geodetic latitude

e^2 = square of the first eccentricity (WGS 84 Ellipsoid)

5. Free-Air Anomaly (Δg_f) is defined as the difference between observed gravity on the physical surface (P) and normal gravity on the telluroid (Q). The telluroid is defined as that surface where the potential of normal gravity is equal to the actual potential on the physical surface. The height above the ellipsoid at which the normal potential is equal to the actual potential on the physical surface is called the normal height. The gravity anomaly formulas given in section **8** are based on the assumption that the normal height is equal to the elevation of the gravity station.

6. Bouguer Anomaly (Δg_B) is computed through a mass normalization process in which masses above the geoid are removed and mass deficiencies below the geoid are restored to a standard density of 2.670 grams/cm^3. These mass layers are approximated by flat plates of finite thickness, infinite extent, and uniform density. These plates are referred to as Bouguer plates. The gravitational attraction of such a plate can be rigorously computed by the formula:

$$\delta g_B = 2\pi G \rho h$$

where G is the Universal Constant of Gravitation (WGS 84: 6.673 x 10^{-8} cm^3/gram·sec^2),

- ρ is the density of the Bouguer plate in grams/cm^3,
- h is the thickness of the Bouguer plate.

7. Summary of Symbols:

Symbol	Description	
Δg_f	Free-Air Gravity Anomaly	(mgals)
Δg_B	Bouguer Gravity Anomaly	(mgals)
δg_B	Gravitational attraction of Bouguer plate	(mgals)
δg_A	Atmospheric Correction	(mgals)
γ	Theoretical Gravity	(mgals)
g	Observed Gravity	(mgals)
h	Elevation of Observation Site, Land Surface, Space (Airborne), Ice, or Water	(meters)
d	Supplemental Elevation (Depth of Ocean, Lake, Ice, or Instrument)	(meters)
ρ	Density	(grams/cm^3)

The following table lists Bouguer correction factors for various densities which are used in the Anomaly Computations:

	ρ	$2\pi G\rho$
Fresh Water	1.000	0.04193
Salt Water	1.027	0.04305
Ice	0.917	0.03845
Land	2.670	0.11195
Land - Fresh Water	1.670	0.07002
Land - Salt Water	1.643	0.06889
Land and Ice	1.753	0.07350

The WGS 84 parameters used in equations 1 - 4 are as follows:

Semimajor axis	a	= 6,378,137 m
Semiminor axis	b	= 6,356,752.3142 m
Eccentricity	e	= 0.081819190842622
	e^2	= 0.00669437999014
Angular Velocity	ω	= 7,292,115 x 10^{-11} radians/sec $\pm$ 0.1500 x 10^{-11} radians/sec
Flattening	f	= 0.00335281066474 (unitless)
Normal Equatorial Gravity	γ_e	= 9.7803253359 m/sec^2
Normal Gravity at Poles	γ_p	= 9.8321849378 m/sec^2
Normal Gravity Constant	k	= 0.00193185265241
$m = \frac{\omega^2 a^2 b}{GM}$	m	= 0.00344978650684 (unitless)
Gravitational Constant	GM	= 3,986,004.418 x 10^8 m^3/sec^2 $\pm$ 0.1 x 10^8 m^3/sec^2

8. The computations of free-air and Bouguer anomalies for various types of terrain are provided in the anomaly computations which follow. These computations result from formulas given by Heiskanen & Moritz (Physical Geodesy, 1967, p. 293):

$$\Delta g_f = g_P - \gamma_Q$$

where g_P is the actual gravity measured on the physical surface and γ_Q is the normal gravity on the telluroid surface.

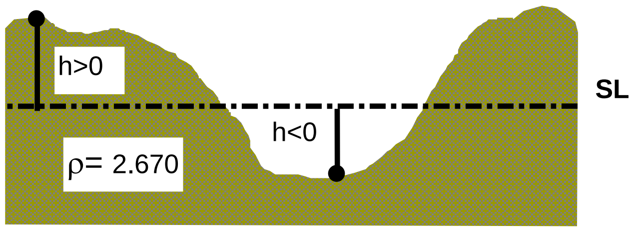
$$\gamma_Q = \gamma_o + \frac{\partial\gamma}{\partial h} H^* + \left(\frac{1}{2!}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right) H^{*2}$$

where γ_o is the normal gravity on the ellipsoid and H* is the normal height.

Elevation of station above MSL (h) is used in the anomaly computations and is assumed equal to H* .

ANOMALY COMPUTATIONS

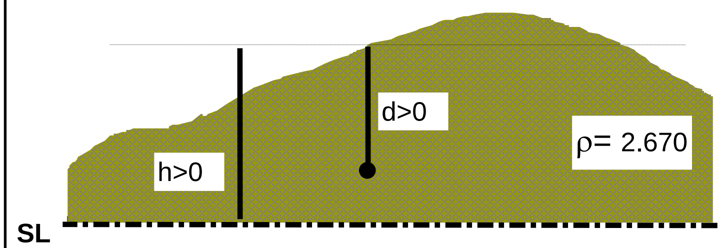
LAND SURFACE (1)



$$\Delta g_f = g - \left(\frac{\partial\gamma}{\partial h}\right)h - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)h^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.11195h$$

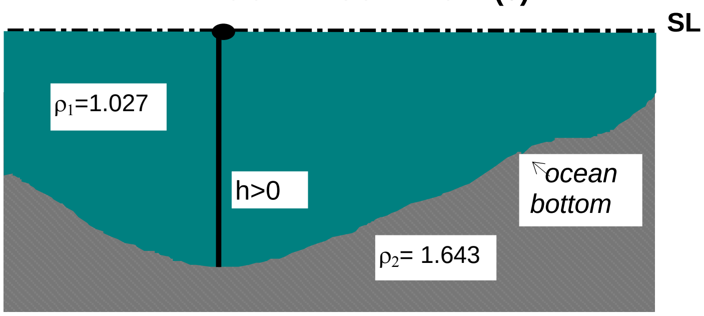
LAND SUBSURFACE (2)



$$\Delta g_f = g + 0.2238d - \left(\frac{\partial\gamma}{\partial h}\right)(h-d) - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)(h-d)^2 - \gamma + \delta g_A$$

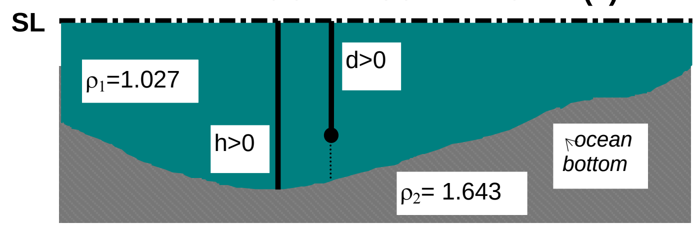
$$\Delta g_B = \Delta g_f - 0.11195h$$

OCEAN SURFACE (3)



$$\Delta g_f = g - \gamma + \delta g_A \qquad \Delta g_B = \Delta g_f + 0.06889h$$

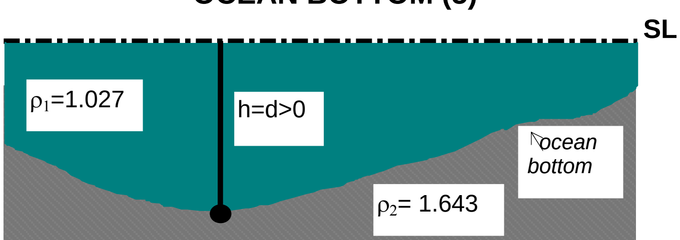
OCEAN SUBMERGED (4)



$$\Delta g_f = g + 0.08608d + \left(\frac{\partial\gamma}{\partial h}\right)d - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)d^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f + 0.06889h$$

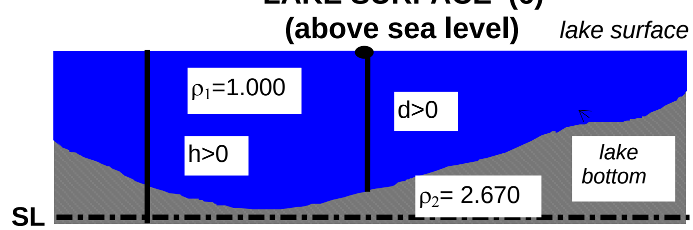
OCEAN BOTTOM (5)



$$\Delta g_f = g + 0.08608d + \left(\frac{\partial\gamma}{\partial h}\right)d - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)d^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f + 0.06889d$$

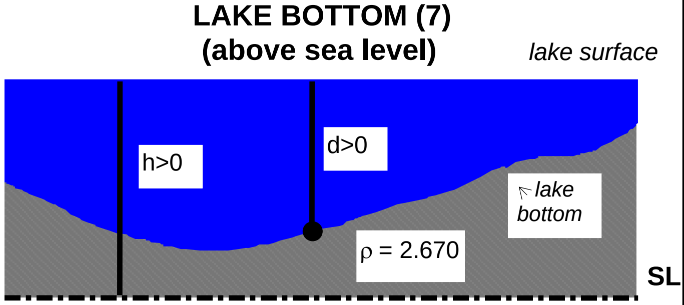
LAKE SURFACE (6)
(above sea level)



$$\Delta g_f = g - \left(\frac{\partial\gamma}{\partial h}\right)h - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)h^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.04193d - 0.11195(h - d)$$

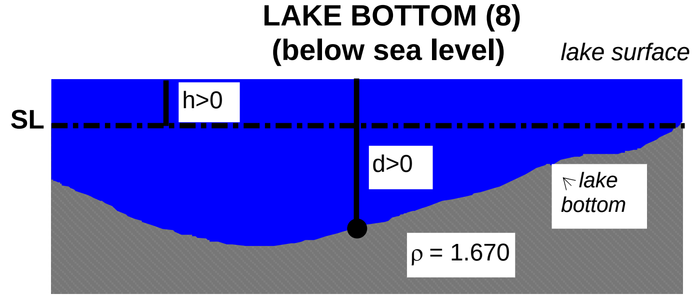
LAKE BOTTOM (7)
(above sea level)



$$\Delta g_f = g + 0.08382d - \left(\frac{\partial\gamma}{\partial h}\right)(h-d) - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)(h-d)^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.11195(h - d) - 0.04193d$$

LAKE BOTTOM (8)
(below sea level)

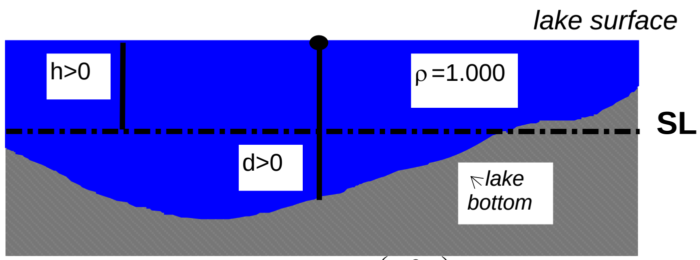


$$\Delta g_f = g + 0.08382d - \left(\frac{\partial\gamma}{\partial h}\right)(h-d) - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)(h-d)^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.07002(h - d) - 0.04193h$$

ANOMALY COMPUTATIONS (CONT.)

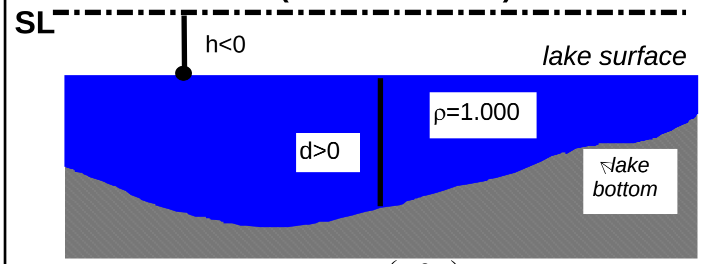
LAKE SURFACE (9)
(above SL with bottom below SL)



$$\Delta g_f = g - \left(\frac{\partial\gamma}{\partial h}\right)h - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)h^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.07002(h - d) - 0.04193h$$

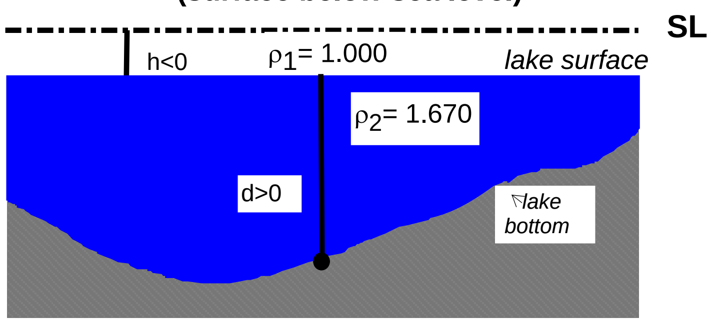
LAKE SURFACE (A)
(below sea level)



$$\Delta g_f = g - \left(\frac{\partial\gamma}{\partial h}\right)h - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)h^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.11195h + 0.07002d$$

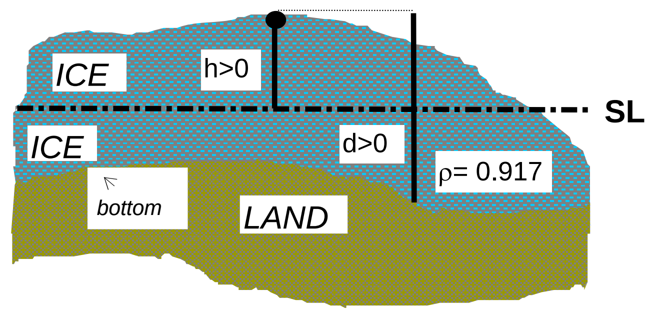
LAKE BOTTOM (B)
(surface below sea level)



$$\Delta g_f = g + 0.08382d - \left(\frac{\partial\gamma}{\partial h}\right)(h-d) - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)(h-d)^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.11195h + 0.07002d$$

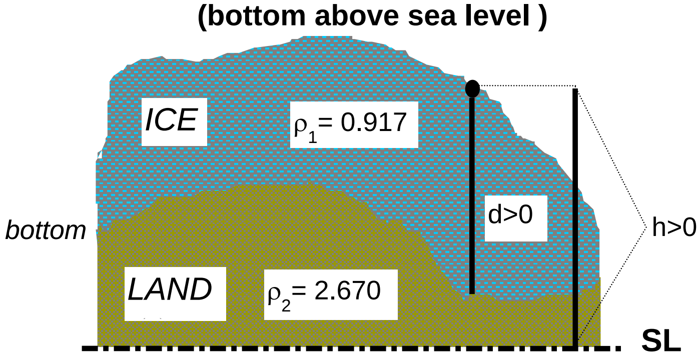
ICE CAP (C)
(bottom below sea level)



$$\Delta g_f = g - \left(\frac{\partial\gamma}{\partial h}\right)h - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)h^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.03845h - 0.07350(h - d)$$

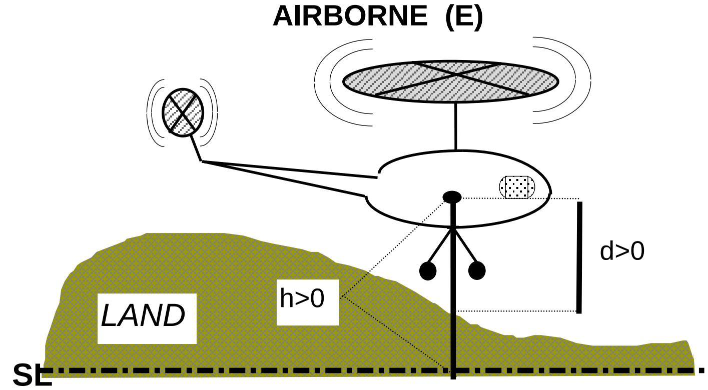
ICE CAP (D)
(bottom above sea level)



$$\Delta g_f = g - \left(\frac{\partial\gamma}{\partial h}\right)h - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)h^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.03845d - 0.11195(h - d)$$

AIRBORNE (E)



$$\Delta g_f = g - \left(\frac{\partial\gamma}{\partial h}\right)h - \left(\frac{1}{2}\right)\left(\frac{\partial^2\gamma}{\partial h^2}\right)h^2 - \gamma + \delta g_A$$

$$\Delta g_B = \Delta g_f - 0.11195(h - d)$$

NOTE

1. **The darkened dot in the above illustrations depicts the location of gravity measurement.**
2. **Type F data is incomplete.**
3. **Type 0 represents gridded data.**
4. **Airborne data is received from outside sources and the above equation may not be used for all types of airborne surveys.**

POINT GRAVITY ANOMALY DATA FORMAT: (80 CHARACTER RECORD)

Column(s) Description

```
1 - 2     Classification:   "U " or "20" - Unclassified
                             "F2" or "32" - Limited Special Release
                             "F4" or "34" - Proprietary
4         Sign of Latitude
5 - 10    Latitude:        (DDMMmm)
12        Sign of Longitude
13 - 19   Longitude:       (DDDMMmm)
21        Type Elevation:  Code:  Description:
                             0    Grid
                             1    Land Surface
                             2    Land Subsurface
                             3    Ocean Surface
                             4    Ocean Submerged
                             5    Ocean Bottom
                             6    Lake Surface (Above Sea Level)
                             7    Lake Bottom (Above Sea Level)
                             8    Lake Bottom (Below Sea Level)
                             9    Lake Surface
                                    (Above Sea Level - Bottom Below)
                             A    Lake Surface (Below Sea Level)
                             B    Lake Bottom (Surface Below Sea Level)
                             C    Ice Cap (Bottom Below Sea Level)
                             D    Ice Cap (Bottom Above Sea Level)
                             E    Airborne
                             F    Miscellaneous Data
23 - 29   Elevation / Depth:  XXXXXXx meters
                             (If Column 21 = 3, 4 or 5 then Ocean Depth is
                              Positive Downward.)
31 - 35   Supplemental Elevation:  (XXXXx)
37 - 42   Observed Gravity:  (Less 976,000 mgals)  (XXXXxx) mgals
44        Sign of Free-Air Anomaly
45 - 48   Free-Air Anomaly:  (XXXx) mgals
50        Sign of Bouguer Anomaly
51 - 54   Bouguer Anomaly:  (XXXx) mgals
56        Isostatic Anomaly or Terrain Correction in Original Document:
                             Code:  Description:
                              0    No information on either
                              1    Terrain Correction given
                              2    Isostatic Anomaly given
                              3    Both quantities given
57 - 61   DoD Gravity Library Assigned Source Number
63 - 66   DoD Reference Base Station (RBS) Number
67        DoD RBS Site
69 - 72   Station Sequence Number or Track Number
76 - 77   Free-Air Anomaly Estimated Accuracy in mgals (Standard Deviation)
79 - 80   Bouguer Anomaly Estimated Accuracy in mgals (Standard Deviation)
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