# 12.221 Field Geophysics – Lecture 3

1) Introduction to gravity – measurement and interpretation
2) Practice with gravimeter

Reading: Chapter 2 of 12.501 lecture notes (Rob van der Hilst)

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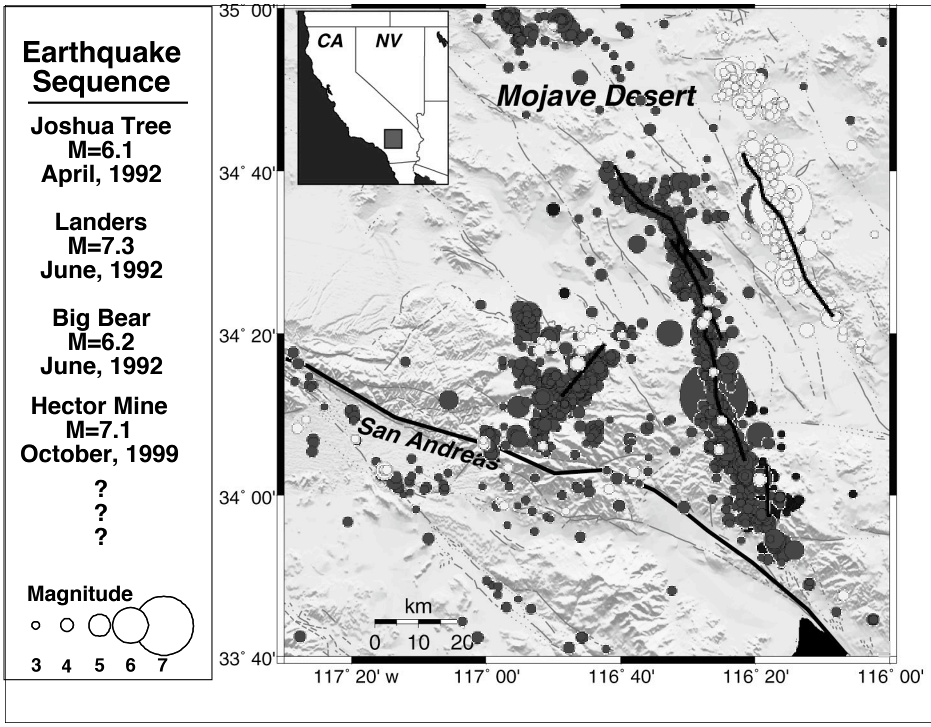


**Earthquake Sequence**

**Joshua Tree**
**M=6.1**
**April, 1992**

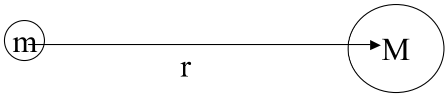
**Landers**
**M=7.3**
**June, 1992**

**Big Bear**
**M=6.2**
**June, 1992**

**Hector Mine**
**M=7.1**
**October, 1999**

**?**
**?**
**?**

# Gravity – simple physics



- Force: $f = GmM/r^2$
  $G = 6.67\ 10^{-11}\ m^3kg^{-1}s^{-2}$
  Vector directed along r
- Acceleration of test mass: $g = GM/r^2$
- Potential energy:
  $U = -GmM/r$
- Gravitational potential
  $V = GM/r$

$$g = -\nabla \bullet V$$

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# Gravity – distributed density $\rho(x,y,z)$

$$\nabla^2 V = 4\pi G\rho$$
$$g = -\nabla V$$

- acceleration
  Recall Gauss' theorem:
- potential

Measuring g places constraints on $\rho(x,y,z)$

Measuring g does not constrain $\rho$ directly (sphere ⇔ point mass)

$\rho(x,y,z)$ can be complicated
⇔ simple physics, complicated interpretation

# Measuring *variations in* g

- f = mg = ku
- g ~ 9.8 m/s$^2$
- g ~ 980 cm/ s$^2$ (980 gals - Galileo)
- Δg ~ 1 mgal ($10^{-6}$) interesting
- Need good instrument, good theory!

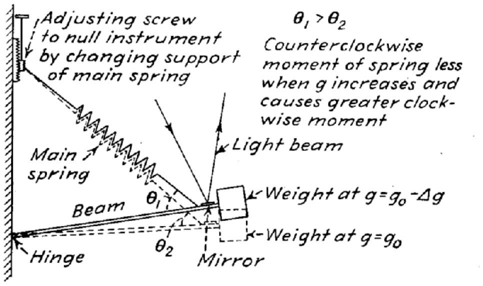
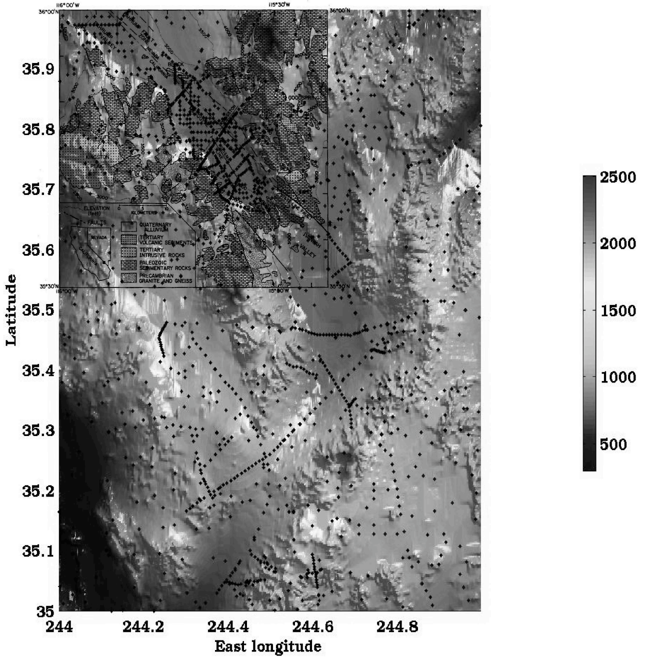
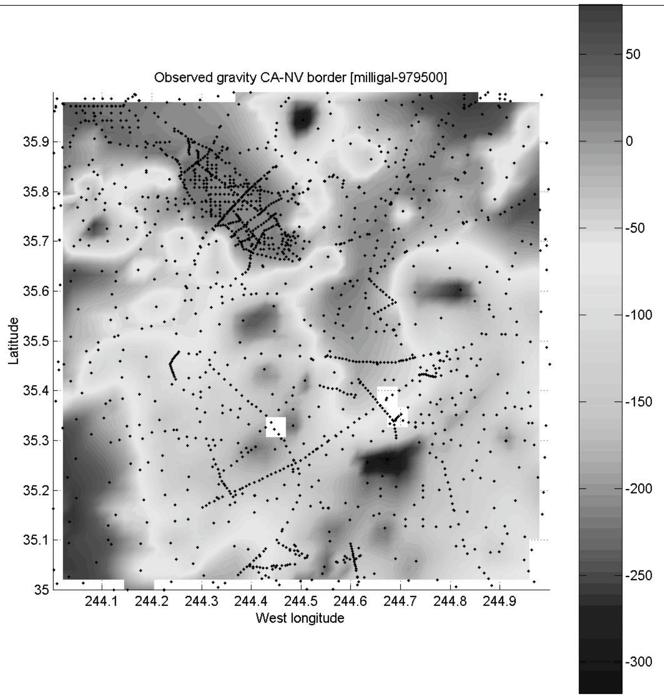


FIG. 4-12. LaCoste-Romberg gravimeter (schematic).

**CA-NV border, topography (meters) and locations of gravity measurements**




Observed gravity CA-NV border [milligal-979500]
Latitude
35.9
35.8
35.7
35.6
35.5
35.4
35.3
35.2
35.1
35
244.1
244.2
244.3
244.4
244.5
244.6
244.7
244.8
244.9
West longitude
50
0
-50
-100
-150
-200
-250
-300

What causes these variations?

Spinning Earth -> centrifugal force, equatorial bulge
- centrifugal force => less g at equator, no effect at poles
- equatorial bulge (~elliptical)
  - more mass near equator => g increases
  - r larger at equator => g decreases

Dependence of g on latitude ($\phi$)

$$g(\phi) = 978032(1 + 0.0052789 \sin^2\phi - 0.00000235\sin^4\phi) \text{ mgal}$$

Elevation change r -> r + h => g decreases (“free air” effect)

Free air correction:

$$g(r+h) = g(r) + (dg/dr)\, h$$

$$dg/dr = -2g/r = -0.307 \text{ mgal/m}$$

# Gravity anomalies

In general:

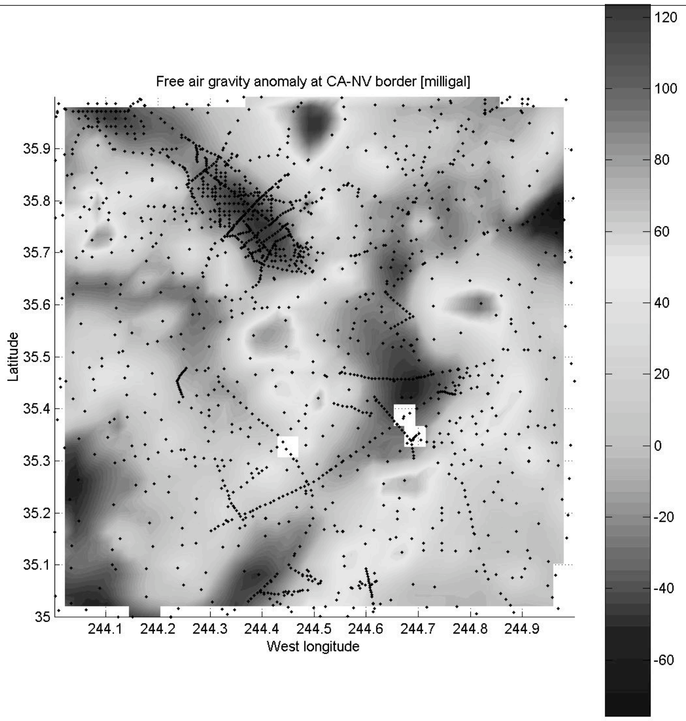
$$\Delta g = g_{observed} - g_{theory}$$

Free Air theory:

$$g_{Free\ Air} = g(\phi,h) = g(\phi) - 0.307\, h$$

Free air anomaly:

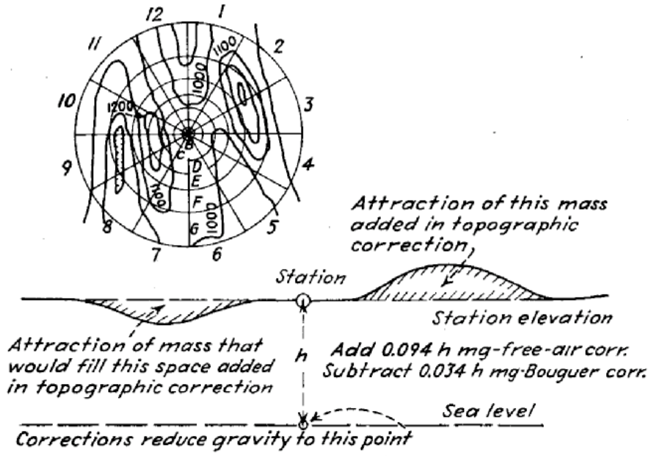
$$\Delta g_{faa} = g_{observed} - g_{Free\ Air}$$



# Bouguer gravity anomaly

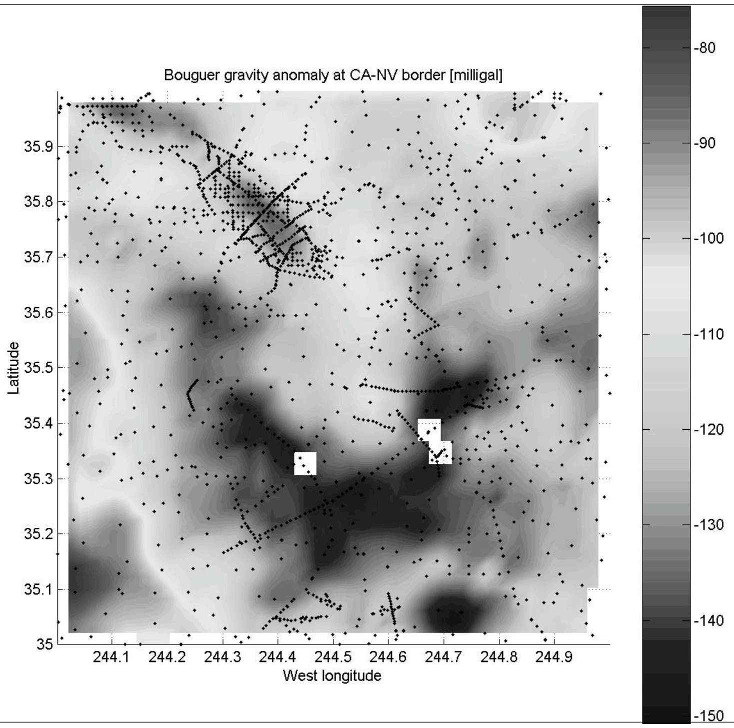
$g_{Bouguer} = g_{Free\ Air} + 2\pi\rho Gh$ + terrain;

for $\rho = 2.67$, $2\pi\rho G = 0.112$ mgal/m



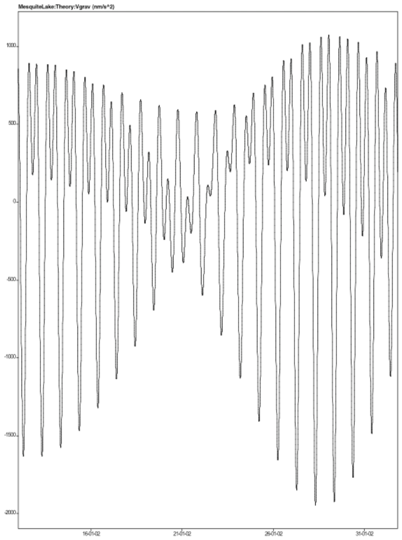
h in feet!

FIG. 3-2. Reduction of gravity values to the geoid. Inset shows typical zone chart used to obtain topographic corrections superimposed over contour map of area. Station is at elevation of 1,050 ft. Average elevation of zone 12-D, for example, is 1,020 ft. Hence topographic correction for this zone is 30 times the constant for the zone.



Isostacy: Mass in each column assumed to be equal

## Tides?

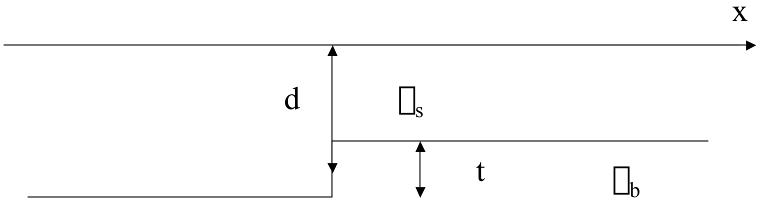


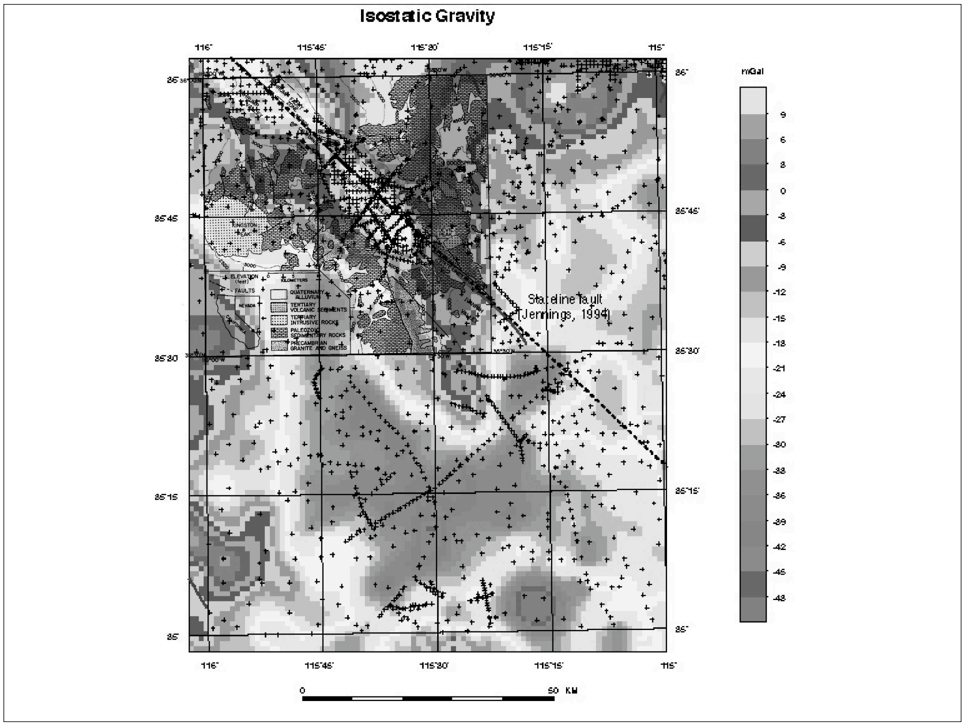
www.astro.oma.be/SEISMO/TSOFT/tsoft.html

## Step in basement topography

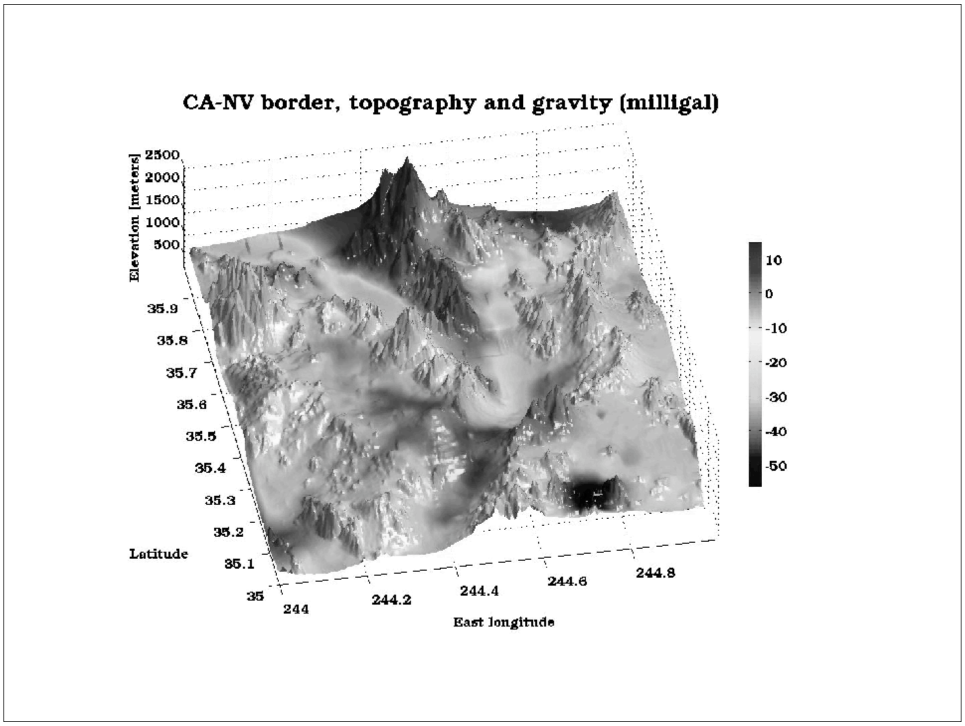
$$g=2G(\square\square)t[\square/2+\tan^{-1}(x/d)]$$

How big a step makes 0.1 mgal?





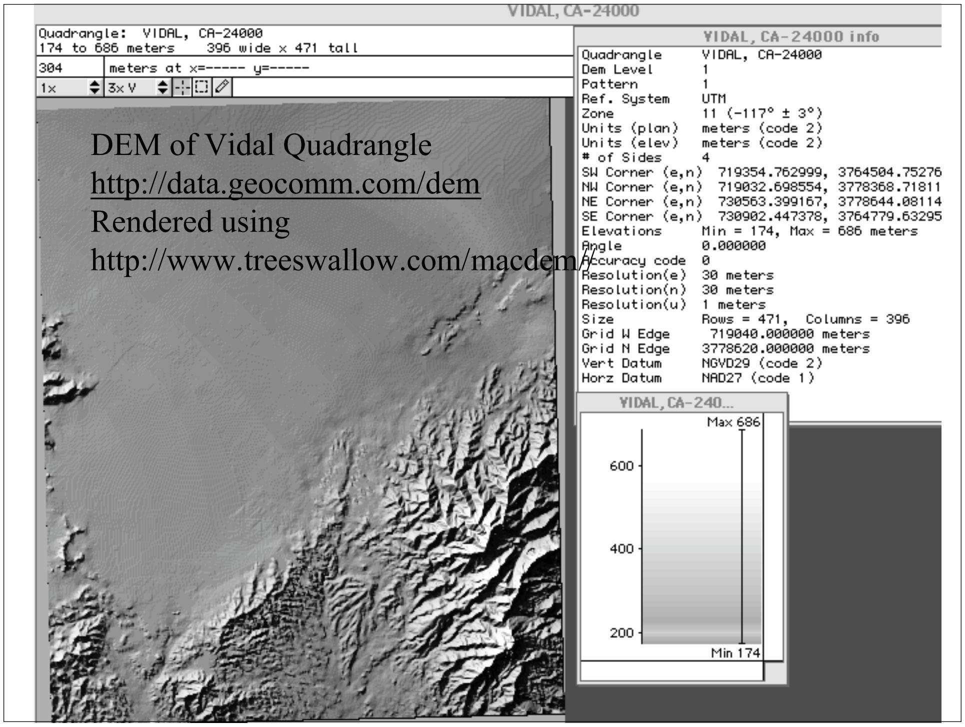
## Isostatic Gravity



## CA-NV border, topography and gravity (milligal)

# Example “real-world” problems:

- Are the mountains isostatically compensated?
- How deep is basin fill in Mesquite basin?
- How steep is the basin boundary?
- Is Table Mountain a plug or a flow?
- Is Black Butte autochthonous?
- . . . . . . . . . . . ?



DEM of Vidal Quadrangle
http://data.geocomm.com/dem
Rendered using
http://www.treeswallow.com/macdem//

```
Quadrangle:  VIDAL, CA-24000
174 to 686 meters    396 wide x 471 tall
304        meters at x=----- y=-----
```

```
Quadrangle      VIDAL, CA-24000
Dem Level       1
Pattern         1
Ref. System     UTM
Zone            11 (-117° ± 3°)
Units (plan)    meters (code 2)
Units (elev)    meters (code 2)
# of Sides      4
SW Corner (e,n)  719354.762999, 3764504.75276
NW Corner (e,n)  719032.698554, 3778368.71811
NE Corner (e,n)  730563.399167, 3778644.08114
SE Corner (e,n)  730902.447378, 3764779.63295
Elevations      Min = 174, Max = 686 meters
Angle           0.000000
Accuracy code   0
Resolution(e)   30 meters
Resolution(n)   30 meters
Resolution(u)   1 meters
Size            Rows = 471,  Columns = 396
Grid W Edge      719040.000000 meters
Grid N Edge     3778620.000000 meters
Vert Datum      NGVD29 (code 2)
Horz Datum      NAD27 (code 1)
```

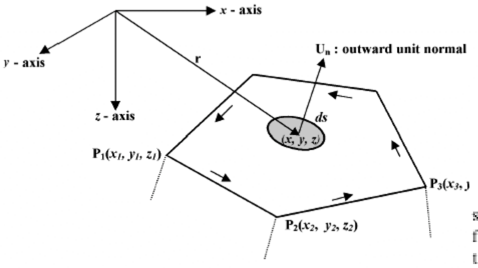
## Computation of terrain & root using DEM – a new solution to a classic problem

**New method for fast computation of gravity and magnetic anomalies from arbitrary polyhedra**

Bijendra Singh* and D. Guptasarma*

GEOPHYSICS, VOL. 66, NO. 2 (MARCH-APRIL 2001); P. 521–526, 1 FIG.

Apply Gauss' theorem & dot product:



$$\mathbf{F} \cdot \mathbf{a} = -G\rho \iint (1/r)\,\mathbf{a} \cdot \mathbf{u_n}\, ds, \qquad (1)$$

$$\mathbf{F} = G\rho \iint (1/r)(\mathbf{r}/r) \cdot \mathbf{u_n}\, ds = G \iint (\rho\mathbf{r} \cdot \mathbf{u_n})/r^2\, ds$$

$$= G \iint \sigma'\, ds/r^2. \qquad (2)$$

Thus, the attraction from a solid body, at the origin, is the same as that from a fictitious distribution of masses on its surface, the surface mass density ($\sigma'$) everywhere taken to be equal to the product

$$\sigma' = \rho\mathbf{r} \cdot \mathbf{u_n}. \qquad (3)$$

See http://www.geo-online.org/manuscript/singh99063.pdf for Matlab scripts for carrying out calculations

## Gravity data: www.scec.org; on web page

```
#                                                                                  #
# Southern California Gravity Data (point measurements)                            #
#                                                                                  #
# Contributed to the Southern California Earthquake Center by                      #
#        Dr. Shawn Biehler of University of California at Riverside                  #
#        on December 14, 1998.                                                       #
#                                                                                  #
# Notes:                                                                           #
#        0) Stations name used by Shawn Biehler.                                     #
#        1) Latitude and longitude were given to 1/100 minute.  Here they are given in #
#           decimal degrees.                                                         #
#        2) Elevation is given in meters above sea level.  Original was in feet.  The #
#           column 'E' denotes the method of determining elevation:                  #
#                  T => orginal in tenths of feet (method unspeficied)                 #
#                  M => map contour (accuracy 1 foot)                                  #
#                  B => bench mark (acurracy 1 foot)                                   #
#                  U => useful (accuracy and method unspecified)                       #
#        3) Raw gravity - 978000.00 mgals (original accuracy 0.01 mgals)             #
#        4) Predicted gravity - 978000.00 mgals, from XXXXX                          #
#        5) inT  -> inner terraine correction, 0 - 1km box.                          #
#           outT -> outer terrane correction, 1 - 20 km box.                         #
#           T    -> method of inner terrane correction.                              #
#        6) FAA - Free Air Anomaly (mgals) (original accuracy 0.01 mgals).           #
#        7) BOUG -Bouger Anomaly (mgals) (original accuracy 0.01 mgals)              #
#        8) map - quadrangle map location of stations - first 3 letters denote map,  #
#                 digits indicate site marked on map.                                #
#                                                                                  #
# stat   lat       long     elev   E  Raw g   Pred g   inT   outT  T    faa     boug   map  #
#..... ........ .......... ....... . ........ ........ ..... ..... . ....... ....... ......#
RO2050 34.96100 -119.44650  889.07 T  1494.47  1742.24  0.32  0.97 G   26.59  828.43 BLC_11
RO2048 34.96667 -119.44000  848.84 T  1498.36  1742.72  0.64  1.08 G   17.59  824.35 BLC_12
RO2020 34.95800 -119.43800  922.29 T  1485.64  1741.98  0.32  1.07 G   28.27  826.49 BLC_10
```

# Homework:

1) Gravimeter practice
2) Gravimeter problem set
3) Calculate expected dial reading at field camp
4) Get tidal corrections (1 person)
5) Maps for Vidal quadrangle and vicinity:
    - Topography (DEM)
    - Observed gravity
    - Free air gravity
    - Bouguer gravity
    - Isostatic gravity