Bull Inf Gravimet Int
67 : 205-209 (1990)

ABSOLUTE GRAVITY MEASUREMENTS DURING THE JULY 22, 1990 TOTAL SOLAR ECLIPSE IN FINLAND

Jaakko Mäkinen

Geodetic Institute, Ilmalankatu 1A, SF-00240 Helsinki, Finland

Abstract. A 52-hour series of measurements with the JILAG-5 absolute gravimeter was made in order to look for variation in gravity, due to hypothetical shielding of the Sun's attraction by the Moon during the eclipse. The standard deviation of 507 six-minute averages, each consisting of 50 drops, was 3.7 μgal, and after long-period phenomena was removed, 2.5 μgal. No anomalous variation was detected.

1. Introduction.

In order to explain apparent irregularities in the motion of the Moon, Bottlinger in 1912 proposed that gravitational attraction between two point masses might be weakened by absorption by intervening matter according to the law

$$F = F_o \exp(- \int \lambda \rho \, dr)$$

also called Majorana gravitational shielding (see e.g. the review paper by Caputo, 1977). Here F_o is the attractive force with no shielding, ρ is the density of the matter, λ is the "coefficient of absorption" and the integral is taken along the line joining the two points. Bottlinger found that the value[1] $\lambda = 3 \times 10^{-15}$ g^{-1}cm^2 would explain the irregularities, which, however, were just errors in the time standard based on Earth rotation (Caputo, 1977).

Since then, most empirical investigations of gravity absorption have brought null results, i.e., no detectable absorption. The outcome is then a bound on the absorption coefficient λ, based on the estimated accuracy of the experiment. Three main types of observations have been used: laboratory experiments, variation in apparent gravity (magnitude and direction) during solar eclipses, and the motion of celestial bodies. Gillies (1987) gives an extensive bibliography.

In laboratory experiments, Majorana (1920) found a positive effect, $\lambda = 2...7 \times 10^{-12}$ g^{-1}cm^2, depending on the material of the shield. The latest laboratory-scale measurement is apparently that of Braginsky and Martynov (1968), yielding a null result $\lambda < 1 \times 10^{-12}$ g^{-1}cm^2.

If the absorption law is valid, the moon acts as a shield during an eclipse and the attraction of the Sun decreases in the zone where the Sun is at least partially obscured. Were the whole Earth uniformly subjected to the same decreased attraction, the earth-bound observer would only see the effect in the solar tide. It would be modified in the same proportion as the solar attraction, i.e. extremely little in absolute terms. However, since the decrease hits a relatively small slice of the Earth, to first order the plain decrease itself should be observed (excluding e.g. secondary atmospheric attraction effects due to temperature changes). This should work independently whether the Sun is below or above the horizon of the observation site. So far all experimental work seems to have been done with "visible" eclipses. Then gravimeters should show a increase in gravity. The plumb line (down) should be pushed away from the sun, whether below or above the horizon.

To give an idea of the magnitudes involved: One μgal is about 1.7×10^{-6} of the total solar attraction. For the February 15, 1961 eclipse Slichter et al. (1965) calculated that the decrease δa (in μgal) in attraction towards the Sun at totality and the absorption coefficient lambda (in g^{-1}cm^2) were related by

$$\lambda = 1.42 \times 10^{-15} \, \delta a$$

---

[1] In accordance with previous literature cgs-units are used here throughout.

So in order to constrain λ below 1 x 10^{-15} $g^{-1}cm^2$ it suffices to constrain gravity change below 0.7 μgal for a zenithal (or nadiral) eclipse, or to constrain the change in plumb line below 0.14 milliseconds of arc for an eclipse close to the horizon.

Tidal gravimeters were first used by Brein (1957) and Tomaschek (1955) during the June 30, 1954 eclipse. Results from the February 15, 1961 eclipse were reported by Caputo (1962, 1977), who found $\lambda < 0.6 \times 10^{-15}$ $g^{-1}cm^2$, by Sigl and Eberhard (1961) who only state that λ is certainly below Bottlinger's value 3 x 10^{-15} $g^{-1}cm^2$, and by Tomaschek and Groten (1963) who give $\lambda < 0.7 \times 10^{-15}$ $g^{-1}cm^2$. They all used horizontal pendula. Dobrokhotov et al. (1961), Slichter et al. (1965), and Venedikov (1961) used tidal gravimeters. The most detailed analysis seems to be that by Slichter et al. (1965), who found for the vertical component $\delta a_g < 0.471$ μgal on the 95% level. The elevation of the Sun was 15° which put only 26% of the attraction on the vertical, so $\lambda < 2.6 \times 10^{-15}$ $g^{-1}cm^2$ on the 95% confidence level.

Arnautov et al. (1983) show a plot of absolute gravity measurements during the July 31, 1981 total eclipse in Novosibirsk, but do not comment it. The standard error is about 2 μgal, and no special effect can be seen.

In a different vein (no eclipses), Harrison (1963) noted that shielding of the Sun's attraction by the Earth itself should show up in the tidal amplitude at the period of the solar day, and be discernible in observations made close to the equator, where the tide at this period is very small. His null result was that the amplitude is less than 2 μgal, or $\lambda < 1 \times 10^{-15}$ $g^{-1}cm^2$. With the wealth of tidal observationss accumulated since it should now be possible to improve considerably on that.

The tightest bounds for λ come from observations on the movements of celestial bodies. Russell (1921) pointed out that because of self-shielding the ratio of gravitational to inertial mass would not be the same for the Earth and the Moon. This should show up as an influence of the Sun on the Earth-Moon system. Eckhardt (1990) used the results of lunar laser ranging to show that $\lambda = 0.0 \pm 1.0 \times 10^{-21}$ $g^{-1}cm^2$.

I report here briefly on absolute gravity measurements made in Finland during the July 22, 1990 total solar eclipse. The eclipse was not favorable for gravimetric observations: it took place at sunrise. The altitude of the Sun at totality was only 4.7° at the observation site. That was about the highest one could get in Finland. On the other hand, two permanent tidal stations with clinometers were in the zone of totality. Their results will be published elsewhere.

2. The experiment and results

The absolute gravimeter JILAG-5 of the Finnish Geodetic Institute belongs to the series of six instruments built by J.E. Faller and his associates at the Joint Institute of Laboratory Astrophysics (JILA), National Institute of Standards and Technology and University of Colorado, Boulder (USA). For a description see Faller et al. (1983), Niebauer et al. (1986), Niebauer (1987), Zumberge et al. (1982).

The approximate eclipse statistics are shown below:

Observation site lat = 62°40′ N, long = 30°56′ E, h = 160 m
First contact at 01:02:04 UT
Totality from 01:52:45 to 01:54:11 UT
Maximum at 01:53:28 UT
Altitude of the Sun at maximum 4.7°
Fourth contact at 02:46:50 UT; duration 1 h 44 min 46 s

At totality only 8% of the Sun's attraction is on the vertical. I have not calculated the shielding effect for the present eclipse. Using the value of Slichter et al. (1965) for the February 21, 1961 eclipse as an estimate, the absorption coefficient λ (in $g^{-1}cm^2$) and apparent gravity increase δa_g (in μgal) at totality are related by

$$\lambda = 17 \times 10^{-15}\ \delta a_g$$

We would need to fix δa_g below 0.15 µgal in order to equal the bound of Slichter et al. (1965) for λ, obviously an impossible task. The experiment, however, was a useful exercise in taking a massive amount of absolute gravity data over a short period. Those aspects will be commented in more detail elsewhere.

The gravimeter was set up in the basement of a school on concrete floor (no pier). Drops were made in sets of 50. Each lasted 302 seconds including the reading of meteorological equipment and computing and displaying the results. The measurements were started 25 hours before the eclipse and continued for another 25 hours after it. Before the start the gravimeter had been running on the site for a day and a half. Room temperature variation during the series was 0.5° and atmospheric pressure variation 8 hPa (Figure 1,a). Drop-to-drop scatter in the sets was mostly 12 to 20 µgal, in a few sets up to 27 µgal when people were running around upstairs. The quadratic mean for 507 sets was 17.4 µgal. The raw set means are shown in Figure 1,(b). Altogether 507 sets, 25350 individual drop were made. The on-line computer program had rejected 4 drops. These seemed to be associated with banging doors and the like.

The results were corrected for atmospheric pressure variations using the locally observed pressure and the coefficient 0.3 µgal/hPa. A provisional tidal correction was made using the program by Heikkinen (1978), gravimetric factor 1.164 and zero phase lag. This left a considerable diurnal signal in the observations (Figure 1,c). The standard deviation of one set mean is 3.7 µgal.

There is a 6-minute gap in the observations at 19:00 UT, June 21, when the controlling microcomputer stopped because of a disc write error, and a 30-minute gap at 15:09 UT, June 22, when the isolation device (the super spring) had to be rezeroed because of drift and needed time to ring down. This latter event seems to have caused a jump in the results (Figure 1,c). Possibly the spring had already drifted outside its proper working range before adjustment.

After the variations at the diurnal and at the semidiurnal period and the jump are eliminated, the residual standard error of one set mean is 2.5 µgal (Figure 1, d). Neither Figure 1,(d) nor the enlarged section (± 12 hours around the eclipse) in Figure 2 show any anomalous gravity variation during the eclipse.

3. References

Arnautov, G.P., Yu.D. Boulanger, E.N. Kalish, V.P. Koronkevitch, Yu.F. Stus, and V.G. Tarasyuk., 1983: "Gabl", an absolute free fall laser gravimeter. Metrologia 19, 49-55.

Braginsky, V.B. and V.K. Martynov, 1968: Investigation of the effect of intermediate bodies on gravitational interaction (translation from Russian). Moscow Univ. Phys. Bull. 21, 35-40.

Brein, R., 1957: Die Schwerkraftregistrierungen. Beitrag zur Frage einer Absorption der Schwere. In: Beobachtungen zur Sonnenfinsternis 1954 in Südnorwegen. Deutsche Geod. Kommission B 34, Mitt. Inst. angew. Geod. 16, 30-45, 52.

Caputo, M., 1962: Un nuovo limite superiore per il coefficiente si assorbimiento della gravitazione. Atti della Reale Accademia di Lincei 32, 509-515.

Caputo, M., 1977: Experiments concerning gravitational shielding. In: Gravitazione Sperimentale, ed. B. Bertotti, Atti dei Convegni Lincei 34, 193-211.

Dobrokhotov, Yu.S., N.N. Pariisky, and V.I. Lysenko, 1961: Observations on tidal variations of gravity during the solar eclipse on February 15, 1961. Quatrième Symp. Int. Marées Terrestres, Commun. Obs. Royal Belgique, 188, Série Géophys. 58, 66-69.

Eckhardt, D.H., 1990: Gravitational shielding. Phys. Rev. D 42, 2144-2143.

Faller, J.E., Y.G. Guo, J. Gschwind, T.M. Niebauer, R.L. Rinker, and J. Xue, 1983: The JILA portable absolute gravity apparatus. BGI Bull. Inf. 53, 87-97.

Gillies, G.T., 1987: The Newtonian gravitational constant. An index of measurements. Metrologia 24 (Suppl.), 1-57.

Harrison, J.C.,1963: A note on the paper 'Earth-tide observations made during the International Geophysical Year'. J. Geophys. Res. 68, 1517-1518.

Heikkinen, M., 1978: On the tide-generating forces. Publ. Finn. Geod. Inst. 85, 150 pp.

Majorana, Q., 1920: On gravitation. Theoretical and experimental results. Philos. Mag. 39, 488-504.

Niebauer, T.M., 1987: New absolute gravity instruments for physics and geophysics. Ph.D. thesis, 155 pp. University of Colorado, Boulder, Colorado, 155 pp.

Niebauer, T.M., J.K. Hoskins, and J.E. Faller, 1986: Absolute gravity: a reconnaissance tool for studying vertical crustal motion. J. Geophys. Res. 91, 9145-9149.

Russell, H.N., 1921: On Majorana's theory of gravitation. Astrophys. J. 54, 334-346.

Sigl, R. and O. Eberhard, 1961: Horizontalpendelbeobachtungen in Berchtesgaden während der Sonnenfinsternis vom 15.2.1961. Quatrième Symp. Int. Marées Terrestres, Commun. Obs. Royal Belgique, 188, Série Géophys. 58, 70-75.

Slichter, L.B., M. Caputo, and C.L. Hager, 1965: An experiment concerning gravitational shielding. J. Geophys. Res. 70, 1541-1551.

Tomaschek, R., 1955: Tidal gravity measurements in the Shetlands. Effect of the total eclipse of June 30, 1954. Nature 175, 937-939.

Tomaschek, R. and E. Groten, 1963: Untersuchung von Gravitationswirkungen während der totalen Sonnenfinsternis am 15. Februar 1961. Nachrichten aus dem Karten- und Vermessungswesen, Inst. angew. Geod., Reihe 1, 25, 17-26.

Venedikov, A., 1961: Premiers enregistrements des marées terrestres a Sofia. Quatrième Symp. Int. Marées Terrestres, Commun. Obs. Royal Belgique 188, Série Géophys. 58, 144-148.

Zumberge, M.A., R.L. Rinker, and J.E. Faller, A portable apparatus for absolute measurements of the Earth's gravity. Metrologia 18, 145-152, 1982.

Figure 1. Results.

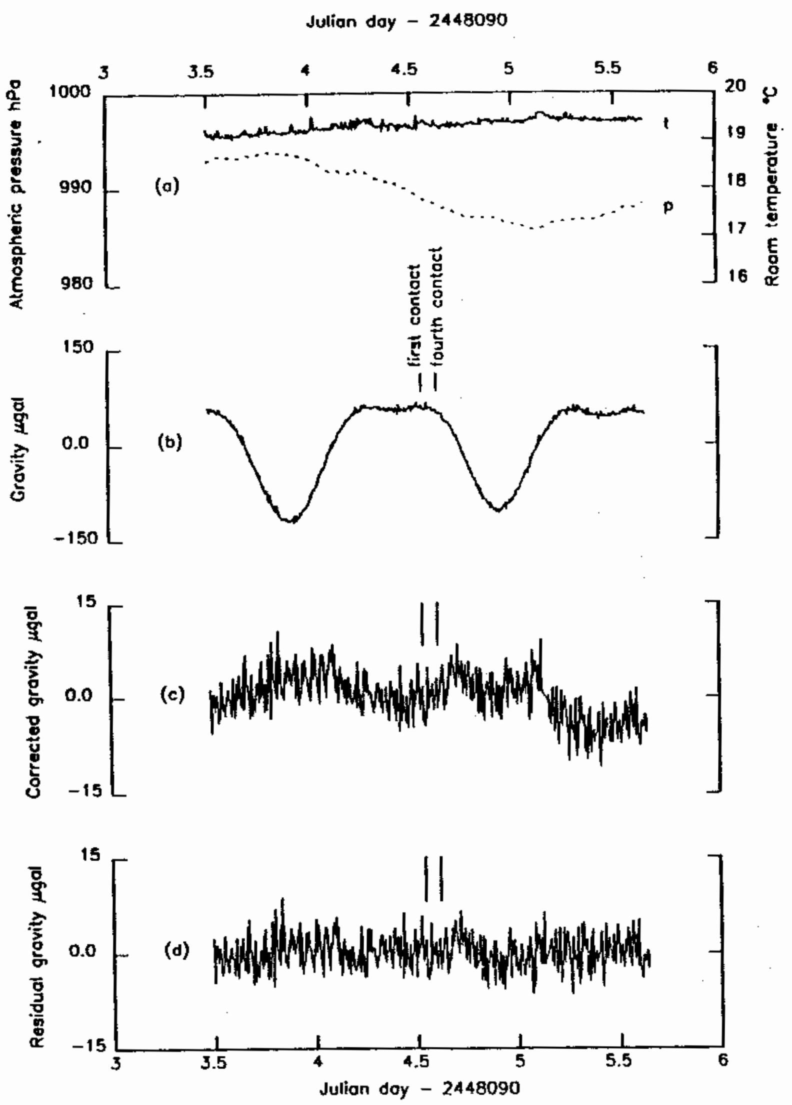
(a) Room temperature variations (solid line) and atmospheric pressure variations (dashed line) during the experiment.

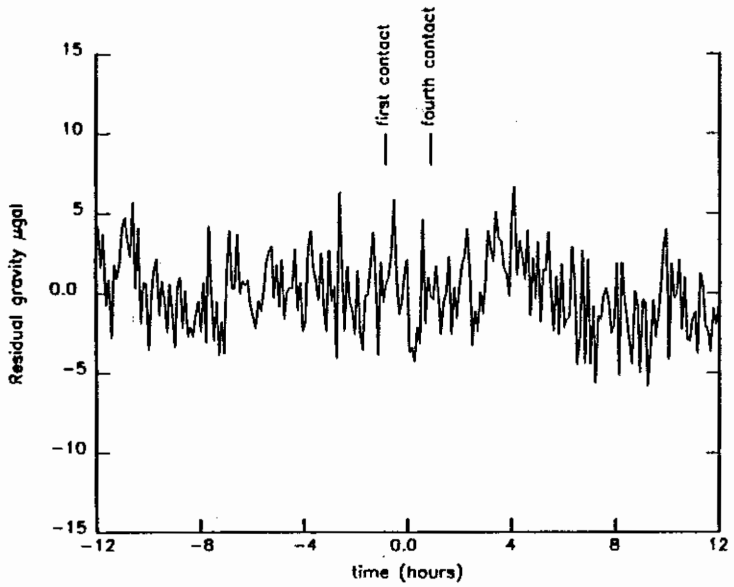
(b) The absolute gravity record. Each data point represents the mean of 50 drops.

(c) Record (b) corrected for tides and variations in atmospheric pressure. There is still considerable variation at the tidal periods. The jump at abscissa 5.1 is commented in the text.

(d) Residuals of (c) after removing the jump and the tidal periods. The two vertical bars point at the beginning and the end of the eclipse. No anomalous variation in gravity can be seen.

Figure 2. Absolute gravity residuals after removing the tidal periods. This is the same as the central part of Figure 1,(d). Time is centered at eclipse maximum. No anomalous variation in gravity is visible.




Residual gravity μgal
15
10
5
0.0
−5
−10
−15
−12
−8
−4
0.0
4
8
12
time (hours)
first contact
fourth contact