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Computation of improved tidal parameters at the gravimetric station of Brasimone

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Abstract
Since 1991 a GWR superconducting gravimeter has been working in a laboratory at the Brasimone ENEA Research Centre, near Bologna (Italy), in the frame of an experimental program to verify Newton's law over distances of the order of 10-100 m. Owing to the aim of the experiment, the gravimeter was moved to different laboratories in the same area, but from August 1995 to date it has been working continuously in the same laboratory in the frame of the preliminary program of the Global Geodynamics Project. The site, belonging to a building of a dismissed nuclear power plant, is free from noise due to human activities, and is thus highly suitable for recording Earth tides. Starting from a set of gravimetric and atmospheric pressure data of high quality relative to 22 months of observation, we performed the tidal analysis using Eterna 3.2 software in order to compute amplitudes, gravimetric factors and phases of the main waves of the Tamura 1987 catalogue. The accuracy of the method adopted for the calibration of the gravimeter, the values of the principal waves and the result of the computation of atmospheric pressure admittance are described.

Key words *Earth tides – tidal analysis*

1. Introduction

In cryogenic gravimeters, the sensitive element is a hollow niobium superconducting sphere which is balanced by the inherently stable magnetic field generated by two superconducting coils supported by two guard coils. The gravimeter signal corresponds to the magnetic force from a feedback coil used to hold the levitating sphere in a fixed position when the gravity changes (Baldi *et al.*, 1995). The stability of the magnetic field and the frictionless bearing of the mass are the basis for a highly sensitive and long-term stable gravimeter in all frequency domains (Richter *et al.*, 1995). The theoretical instrument sensitivity is of the order of 0.01 nm/s^2, but geophysical and environmental noise reduces the effective accuracy to 0.1 or better (Goodkind, 1991).

From August 1995 to date the GWR Superconducting Gravimeter (number T015) has been recording continuously in a laboratory, inside the dismissed nuclear power plant in the research centre of ENEA BRASIMONE (Italian National Institute for Energy Development), located 500 m from the Brasimone lake in the Apennines, between Bologna and Florence (Italy, 44°07′N, 11°07′E, 845 m height). Previously tidal and atmospheric pressure data were collected discontinuously for short periods in 1992, 1993 and 1994; the instrument has been calibrated periodically adopting the method described in the following. The station is ready to participate to the Global Geody-

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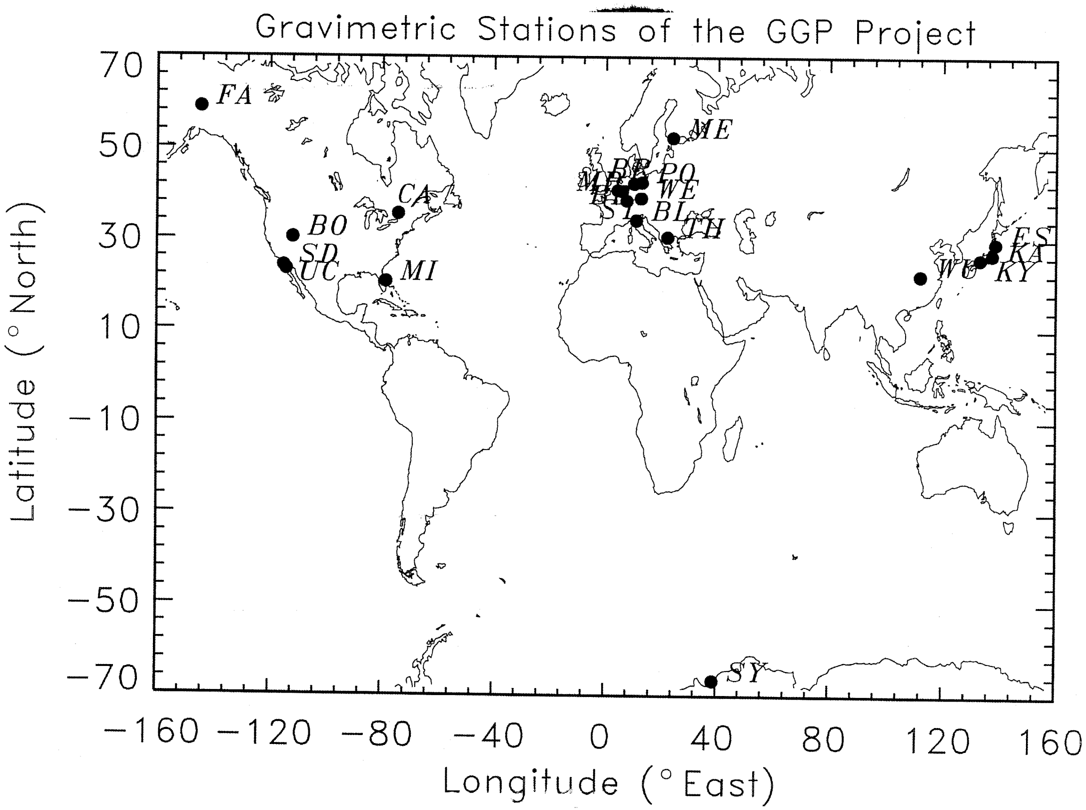

Fig. 1. Scheme of the network of gravimetric stations participating in the Global Geodynamics Project.

namics Project (GGP), which will start in July 1997 with the purpose of monitoring changes in the Earth's gravity field (Crossley and Hinderer, 1994), using a global network of superconducting gravimeters already established (fig. 1). The high sensitivity and stability of these instruments will allow studies on Earth tides and diurnal free wobble, atmospheric interaction, ocean load models, Earth rotation and polar motion, tectonic processes and other scientific tasks.

The measurements will be taken over a time span of 6 years to separate annual and 14 month Chandler Wobble components in the gravity records. The data exchange will be carried out by a standard format and collected periodically at the *International Centre of Earth Tides* using the *internet* protocols.

2. Calibration of the gravimeter

In a superconducting gravimeter a gravity variation acts on the sphere whose position is sensed by an imbalance in a capacitance bridge; this signal is amplified, rectified and applied to the feedback coil (Goodkind, 1991). For this reason it is necessary to measure the calibration constant of the instrument, a factor which converts volts into units of gravity acceleration.

Usually, the calibration method adopted consists in the comparison in the same site of the instrument with an absolute gravimeter; using the tidal effect to produce a significant variation of gravity, this approach gives an accuracy of 1% or better (Hinderer *et al.*, 1991).

In our station a new calibration method is used; it consists in moving a mass of simple geometry (a circular ring with square cross section), along the vertical axis of the instrument, in order to perturb the gravity field in a known way (Achilli *et al.*, 1995; Varga *et al.*, 1995).

A second mass is placed about ten meters away from the gravimeter, and is connected by means of steel cables and pulleys in such a way to balance the weight of the annular mass, (273.40 ± 0.01 kg); a small force applied to the cables by an engine controlled by means of a Personal Computer can easily move the calibrating mass (fig. 2). The system is improved by a wireless digitiser which is able to measure the ring position with an accuracy of 0.1-0.2 mm.

Owing to the simple geometry adopted and to the symmetrical distribution of masses around the gravimeter sphere, the theoretical effect due to the perturbing mass movement is easy to model. The effect of an erroneous determination of the position of the sensible sphere mounted inside a cryostat is estimated to be well below the precision of the method which is about 0.3% (Achilli *et al.*, 1995).

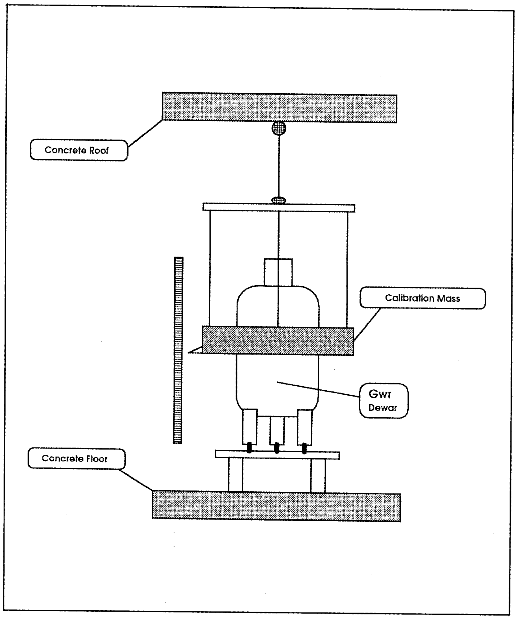

Fig. 2. Scheme of the ring calibration apparatus.

Two calibration procedures have been adopted: the calibration signal scan and the peak-to-peak calibration. The first consists in moving the calibration mass slowly (or step by step) in a period of about 45 min along the gravimeter vertical axis, recording the following observable quantities: time, mass position and the signal of the gravimeter. The theoretical effect of the mass is compared (in the least-square sense) with the signal, corrected for tide and drift, defining the position of maximum and minimum effect due to the mass movement, the position of null effect, corresponding to the sphere centre, and a first value of the calibration constant (fig. 3).

In the peak-to-peak calibration, moving the mass from the position of maximum to the position of minimum effect in a period of 4 min, we produce a calibration square wave (fig. 4). The period of the square wave was chosen to be 8 min to optimise the computation of the gaps given by the perturbing movement of the mass. A mean value of the data for each peak is computed together with the standard deviation of the mean; this calculation gives several peak values for each calibration experiment. Finally the calibration constant is obtained by dividing the theoretical effect: (67.311 ± 0.001) $\mathrm{nm/s^2}$, by the weighted average of the wave amplitude.

Table I lists the results of calibrations performed in the period 1994-1997 together with their standard deviations; the high repeatability (≅ 0.2%) confirms the reliability of the method.

The calibration outlined in the table by the IMGC letters, corresponds to a calibration obtained from a comparison with an absolute gravimeter, performed in May 1994. The *symmetrical rise and fall* absolute gravimeter of the G. Colonnetti Institute of Metrology, Turin was installed for a period of three days, (10/11/12 May 1994) in the same site (Baldi *et al.*, 1995). The comparison agrees with the results of the ring calibration system at a level of 1% or better (table I).

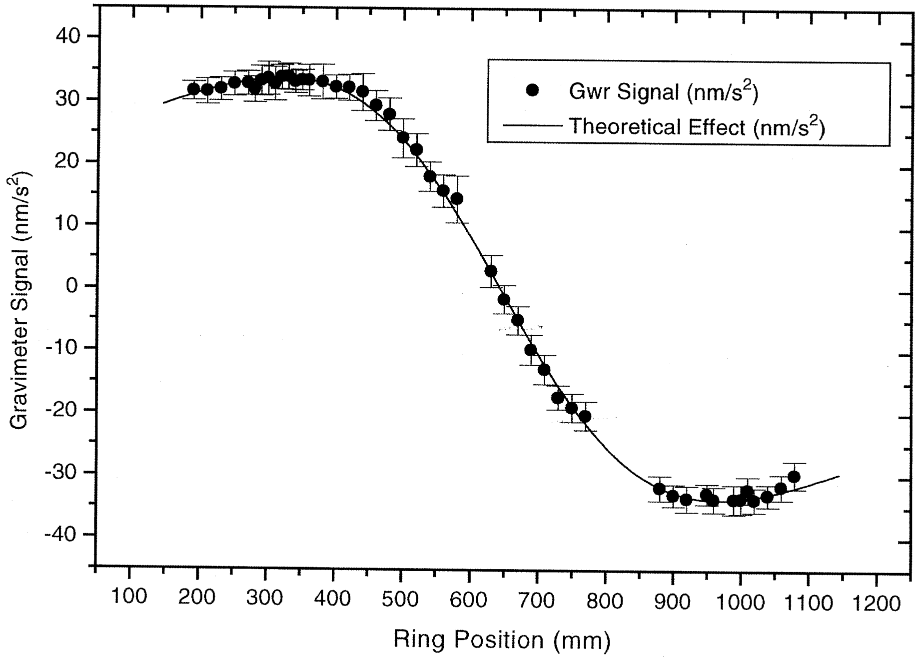

Fig. 3. Example of calibration signal scan: response of the gravimeter to a step-by-step motion of the ring along its vertical axis and theoretical signal.

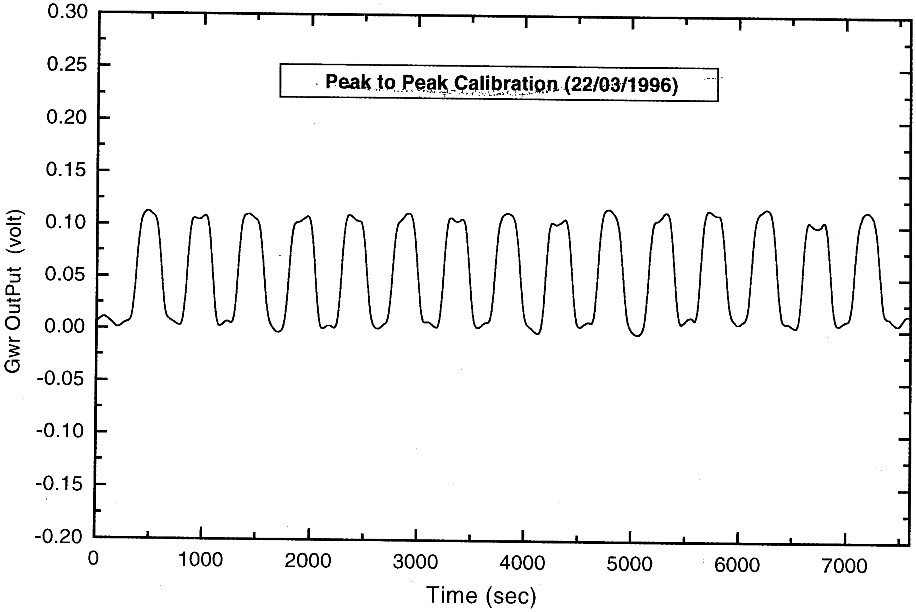

Fig. 4. Example of peak-to-peak calibration: gravimeter recorded signal (after elimination of tidal variations) during the movement of the ring from the position of minimum effect to the position of maximum effect.

Table I. Results of the ring calibration experiments, and of the comparison with the IMGC absolute gravimeter.

Period (year)	Method	Calibration factors (nm*s^{-2}/V)
1994	IMGC-GWR	649.2 ± 3.8
1995	CSS	649.4 ± 1.0
1995	CSS	649.4 ± 1.3
1995	PSC	649.4 ± 1.2
1996	PSC	648.9 ± 1.1
1997	CSS	649.3 ± 3.0

IMGC gravimeter

Date	Drops number	Calibration factors (nm*s^{-2}/V)
1994-5-9,10,11	166	649.2 ± 3.8

3. Tidal analysis

Two types of observables were used in the tidal analysis: the high-resolution gravity signal recorded at a rate of 1 s and the atmospheric pressure recorded at a rate of 20 s. The software adopted (Eterna 3.20) needs a pre-processing approach consisting in a format conversion, calibration of the data using the calibration constant previously computed, graphical elimination of steps of a few nm/s^2, interpolation of gaps not exceeding a few hours and a final decimation to 1 h sample rate. The corrected data were analysed applying the tidal potential development of Tamura (Tamura, 1987), and a linear regression with air pressure, resolving the amplitudes, gravimetric factors and phases of the main tidal bands, the drift component and a mean value of pressure admittance (Wenzel *et al.*, 1994). An alternative computation of the frequency-dependent atmospheric pressure admittance was performed by means of a cross spectrum analysis

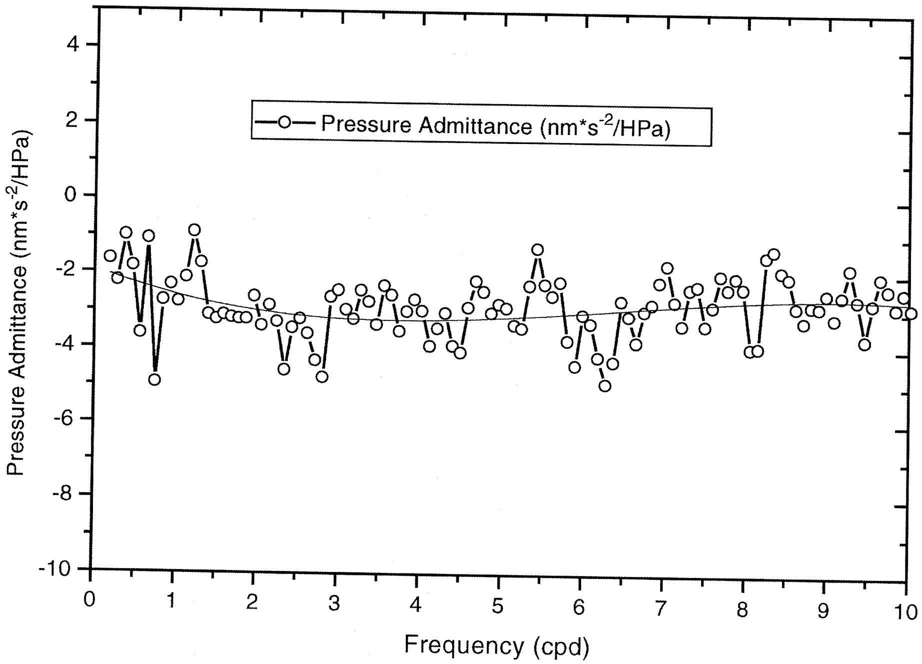

Fig. 5. Real barometric pressure admittance as a function of the frequency.

Table II. Improved tidal parameters computed using data recorded for 22 months at the Brasimone station.

Tidal model computed for the gravimetric station of Brasimone
Tamura 1987 catalogue – 1214 waves

Wave	Amplitude (nm* s^{-2})	Amplitude factor δ	RMS	Phase $\Delta\phi$(°)	RMS
MF	33.45	1.1557	0.0118	−0.61	0.38
*Q*1	68.11	1.1457	0.0013	−0.33	0.07
*O*1	356.17	1.1471	0.0003	0.08	0.01
*M*1	28.04	1.1484	0.0025	0.16	0.14
*P*1	165.88	1.1482	0.0005	0.17	0.03
*S*1	4.89	1.4300	0.0276	10.59	1.59
*K*1	495.19	1.1340	0.0002	0.26	0.01
*PSI*1	4.22	1.2356	0.0196	3.21	1.12
*PHI*1	7.37	1.1855	0.0107	−0.87	0.61
*J*1	28.23	1.1560	0.0032	0.04	0.18
OO	115.39	1.1521	0.0067	0.78	0.39
2*N*2	13.69	1.1567	0.0024	1.77	0.14
*N*2	87.02	1.1740	0.0005	1.76	0.03
*M*2	456.71	1.1797	0.0001	1.20	0.01
*L*2	12.84	1.1733	0.0023	0.47	0.13
*S*2	212.42	1.1793	0.0002	0.07	0.01
*K*2	57.79	1.1802	0.0009	0.33	0.05
*M*3	5.83	1.0660	0.0018	−0.06	0.11

of gravity detided (gravity data minus computed tidal model values) and the pressure signal. The result indicates the expected higher values for lower frequencies (fig. 5), as a consequence of the contribution of the deformation of the Earth's crust (Neumeyer and Dittfeld, 1997). In any case the available data set is not enough to introduce a reliable frequency dependence of pressure admittance; the mean value adopted is -3.03 ± 0.03 nm/s^{-2} HPa^{-1}. This fact, together with the strong instrumental drift, allows us, at the moment, to resolve with high accuracy only the short-period components of the tidal signal (table II); the highpass filtered residuals of the solution (cut-off period of 51 h) give a very low standard deviation of about 2 nm/s^{-2} (fig. 6). The comparison of our results with those obtained by other European gravimetric stations (Baker *et al.*, 1996) is also satisfactory, taking in mind that the accuracy of the different calibration methods adopted is generally lower than 0.1% (fig. 7).

A final computation was made with the purpose of verifying the stability of the calibration constant in time; from the whole available data (1992-1997) six data sets of 120 days were separately analysed adopting the same calibration constant. Improved tidal parameters were computed for each data set; the weighted averages of the gravimetric factors of the principal

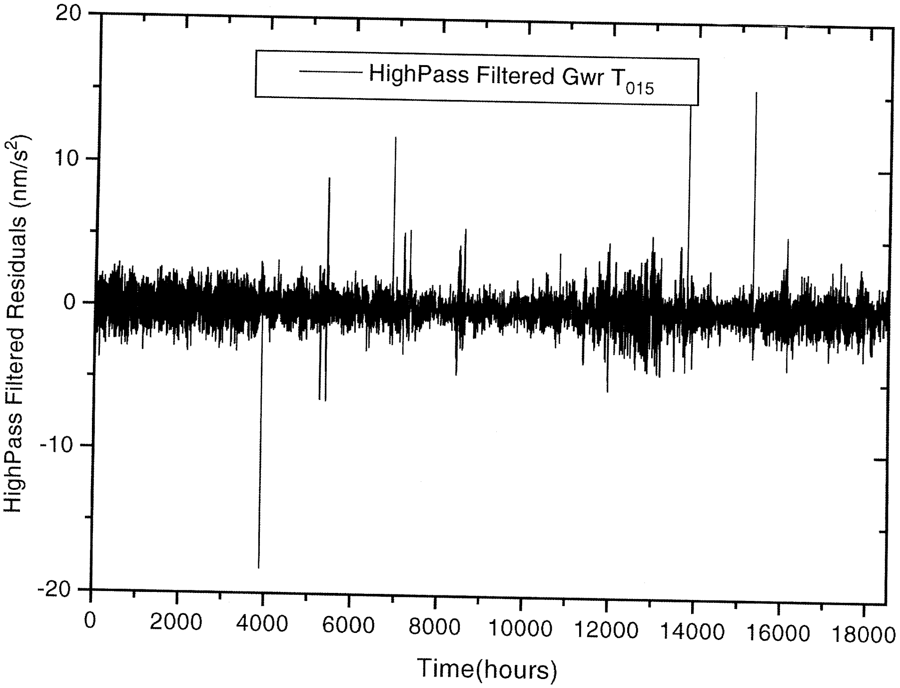

Fig. 6. Example of high-pass filtered residuals of data analysed.

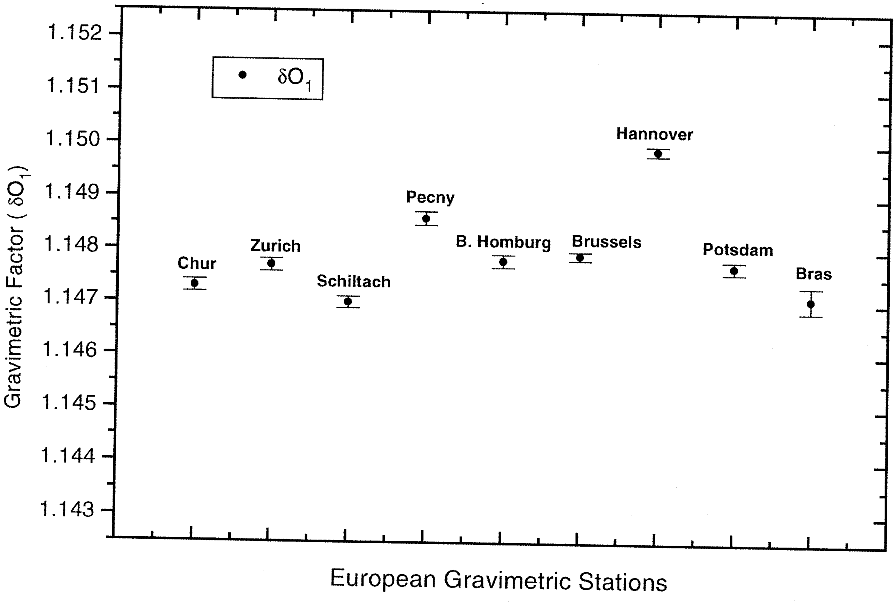

Fig. 7. Comparison between the gravimetric factors of the O_1 diurnal component observed at the permanent European gravimetric stations.

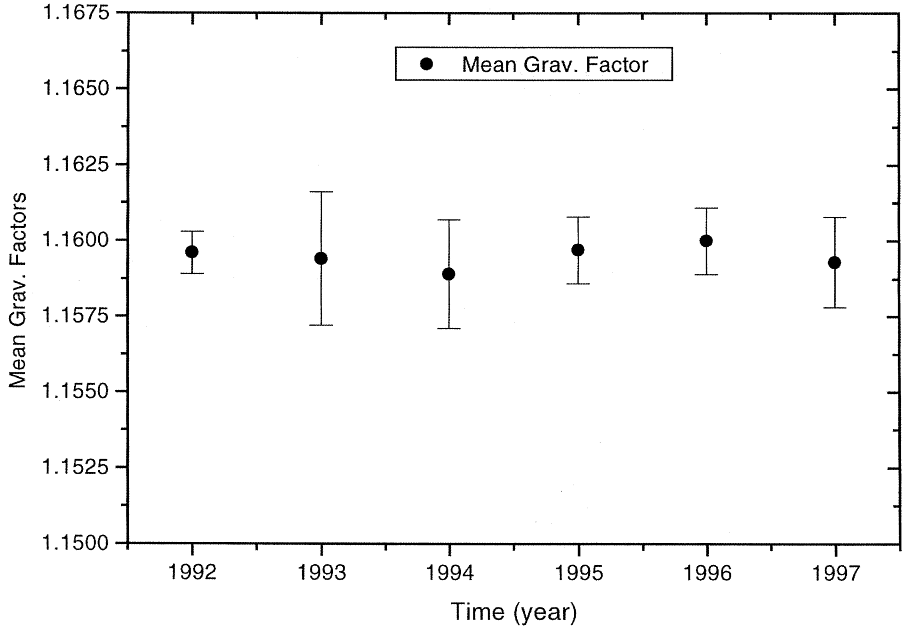

Fig. 8. Mean gravimetric factors (average of principal diurnal and semi-diurnal waves) computed using different data sets recorded from 1992 to 1997.

diurnal and semidiurnal waves (O_1, K_1, M_2, S_2) were estimated together with their standard deviation, obtaining a repeatability of about 0.1% (fig. 8).

4. Conclusions

The GWR superconducting gravimeter, installed in a laboratory inside a dismissed nuclear power plant in the Research Centre of ENEA of Brasimone, starting from August 1995 is involved in the Global Geodynamics Project preliminary activities and is currently recording as one of the tidal stations of the global network.

The gravimeter was calibrated at the level of 0.2% using the effect of a moving mass as reference signal.

A data set of several months was chosen for a preliminary tidal analysis using Eterna software version 3.2, obtaining an improved solution for the amplitudes, gravimetric factors and phases of several diurnal, semi-diurnal and ter-diurnal tidal species of the Tamura development, and a first estimation of the correct air pressure admittance.

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