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The Gravimetric Station of Brasimone

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Abstract.
From 1990 up to now a superconducting gravimeter GWR model TT70 is operating in a laboratory located on the dismissed nuclear power plant of Brasimone, in the Italian Apennines between Bologna and Florence, in the frame of an experiment meant to verify Newton's gravitational law. From July 1995, the gravimeter is involved in the Global Geodynamics Project, and is actually working for high precision tidal analysis and modelling.
In this paper we describe the calibration procedure adopted together with the preliminary results of the tidal analysis performed using the software Eterna 3.20.

Introduction.
Since 1990 the gravimeter GWR T015 is working in different laboratories, in a research center of ENEA (Italian national institute for energy development), located near a lake in the Apennines, 70 Km far from Bologna (Italy, 44° 07' N, 11° 07' E, 845 m above sea level).
The superconducting gravimeter was used in the frame of an experimental program meant to verify the validity of the Newton's law over distances of the order of 10 - 100 m (Achilli et al., 1996).
In 1992 a tidal analysis was performed using a continuative tidal signal relative to a period of five months (Baldi et al., 1995).
From July 1995 the gravimeter is definitively sited in a suitable building in the same area, on the very stable basement of a dismissed nuclear power plant, characterized by a very low noise level.
The set of tidal data (14 month) collected up to now has been analysed using the Eterna 3.2 software.

The Calibration Method.
As well known a superconducting gravimeter converts variations of the local acceleration of gravity in potential differences inside a capacitance bridge, that is an element of the sensing device of the instrument, (Goodkind J.M., 1991). For this reason the gravimeter needs to be calibrated, in other words it is necessary to calculate the calibration constant of the instrument, a factor which converts volts in units (microgal or nm/s^2) of gravity acceleration.
The most used calibration method is the comparison in the same site of the instrument with an absolute gravimeter; using the tidal effect to produce a significant variation of the acceleration 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 gravimeter vertical axis, in order to perturb in a known way the gravity field (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 +/- 0.010 kg); a little force applied to the cables by an engine servo-controlled by means of a Personal Computer can easily move the calibrating mass (Fig. 1).
The system is improved by adding 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, an analytical computation is done to determine the theoretical effect due to the perturbing mass movement.

An erroneous determination of the position of the gravimeter sphere mounted inside a cryostat, is estimated to be well below the precision of the method wich results to be about 0.3%, (Achilli et al., 1995).

Two calibration procedures have been adopted: the calibration signal scan and the peak to peak calibration.

The calibration signal scan consists in moving the calibration mass slowly in a period of about 45 minutes along the gravimeter vertical axis, the following observable quantities are recorded: the mass position, the time and the response of the gravimeter.

A least square adjustment technique is applied to fit the theoretical effect of the mass to the gravimeter response, corrected for the tide and the drift, in order to define the position of maximum and minimum effect due to the mass movement, the position of null effect, corresponding to the sphere center, and a first value of the calibration constant (Fig. 2).

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 minutes, we produce a calibration square wave (Fig. 3).

The period of the square wave was chosen to be 8 minutes to optimise the computation of the gaps given by the perturbing movement of the mass.

A graphical interactive program written with the aid of the IDL graphical libraries on a VAX 4000-90 computer and a mouse device, allows us to edit in a graphical way the calibration square wave data to eliminate disturbances.

After this operation, a mean value of the data for each peak is computed together with the standard deviation of the mean; this calculation gives about 30 peak values for each calibration session, (about 2 hours).

The calibration constant is obtained by dividing the theoretical peak to peak effect: (6.7311 +/- 0.0001) microgal, by the weighted average of the wave amplitude.

In (Tab. I) the results of calibrations performed in the period 1991-1996 are listed together with their standard deviations.

The gravimeter is equipped with an auxiliary tool, the electrostatic calibrator, allowing the measure of the feedback voltage response to a constant electrostatic force applied to the sphere. The electrostatic calibration allows the monitoring of the time stability of the scale factor to better than 0.01 % (Fig. 4).

Fig. 5 represents the comparison between the ring calibration values and the corresponding electrostatic calibrations related to different coil settings (Achilli et. al, 1995). One can observe a strong linear dipendence of the two values. In Fig. 5 is also shown the value of the calibration obtained from the comparison with the absolute gravimeter of the Istituto of Metrologia G. Colonnetti of Turin which was installed for a period of three days, (10/11/12 May 1994) in the same site (Baldi et al., 1995). The comparison is in agreement with the results of the ring calibration system at a level of 1% or better (see Fig. 6 and Tab. I).

Tidal Analysis.

A set of 14 month of data recorded by the gravimeter GWR T015 were used to perform a tidal analysis using Eterna 3.20 program, written by Professor Wenzel of the Geodetic Institute of the University of Karlsruhe (Wenzel et al., 1993).

Two type of observables were used: the high resolution gravity signal recorded at a rate of 1 sec and the barometric signal recorded at a rate of 20 sec.

The Hr_Grav signal was decimated at 5 seconds rate, filtered and converted to a Preterna format by means of the program Alpha, written by J. Neumeier of the University of Potsdam; the barometric signal was decimated at 1 minutes rate and converted to Preterna format in the same way of the Hr_Grav signal.

The pre-elaboration of the gravimetric and barometric data was performed using Preterna 3.20 program, following the known sequence (Wenzel et al., 1994):

a) Calibration.

b) Graphical editing of the calibrated data and elimination of gross disturbances.
c) Computation of model tide and drift.
d) Graphical editing of the detided data and elimination of steps.
e) Automatic depiking, destepping and degapping.
f) Graphical editing of the previously corrected data and elimination of remaining disturbances.
g) Iteration of the points e) and f) until no more data are corrected by the automatic procedure.
h) Numerical filtering and decimation at 5 minutes sampling interval.
i) Numerical filtering and decimation at 1 hour sampling interval.

The final product of the pre-elaboration with Preterna 3.20 is a file corrected for disturbances, for the barometric pressure effect, using a real single barometric admittance, and for the drift (Fig. 7). This file is prepared in a format fully compatible with the elaboration program Eterna 3.20.
After the pre-elaboration a final run with Eterna was performed to estimate: amplitude, delta factors and phase delay of the main tidal wave using the tidal catalogue of Tamura 1987 (1200 waves), (Tamura , 1987). It was also possible to evaluate a single real pressure admittance (Tab. II).
In table II the values of the amplitudes, delta factors and phase for the main tidal waves are listed together with their RMS errors.
An high pass filter, called Pertsev number 2, was used to reduce the noise (Fig. 8 and 9); in fact in our case we have to point out that the barometric noise is not completely eliminated by using a mean real barometric admittance of -2.712 +/- 0.005 nm/s^2*HPa.
In Fig. 8 and 9 the residuals of the analysis previously described are shown. A standard deviation of the residuals of about 3 nm/s^2 results from the final analysis (Tab. II).

Conclusions.

Since July 1995 the gravimeter GWR T015 is continuously recording the tides in the frame of the GGP Project; the instrument is calibrated by means of a new method based on perturbing in a known way the gravitational field by moving vertically a circular ring and recording the gravimeter response.
A first comparison with an absolute gravimeter was performed in may 1994 to verify the correctness of our calibration approach; the results are in agreement at a level of 1%.
The preliminary tidal analysis performed using the Eterna software shows a standard deviation of residuals of about 3 nm/s^2, which may be due to the mean atmospheric pressure adopted.
In the future we hope to be able to reduce the noise of the non tidal effects by performing a cross spectral analysis of the gravimeter residuals versus the barometric pressure; the calibration will be then verified again with the aid of the two methods described below.

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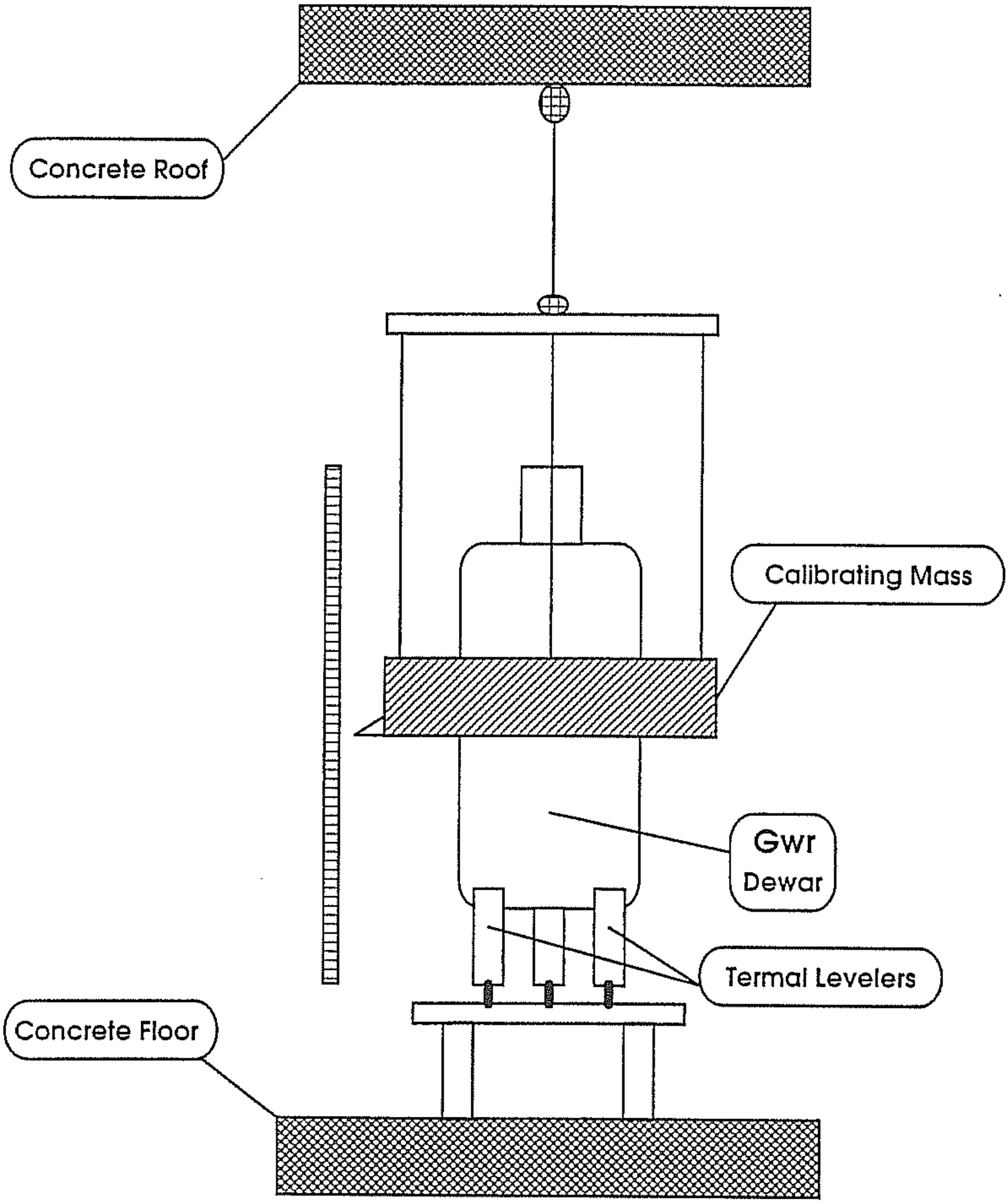

Fig. 1 - Scheme of the ring calibration apparatus.

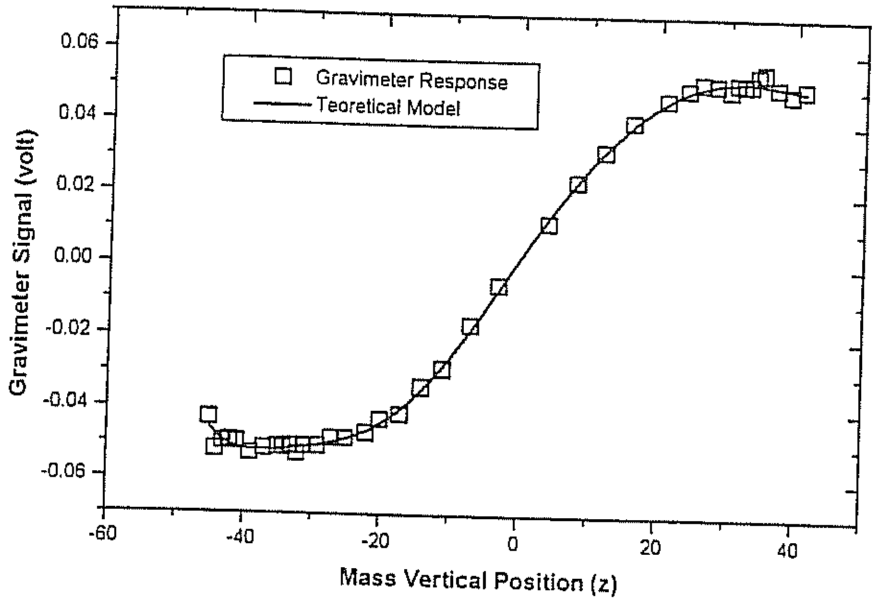

Fig. 2 - Example of Calibration Signal Scan, the response of the gravimeter to a slow motion of the ring along its vertical axis is fitted as a model experiment to the theoretical analytical function, getting: the values of maximum and minimum effect, the position of null effect due to the mass and a first less precise determination of the calibration constant.

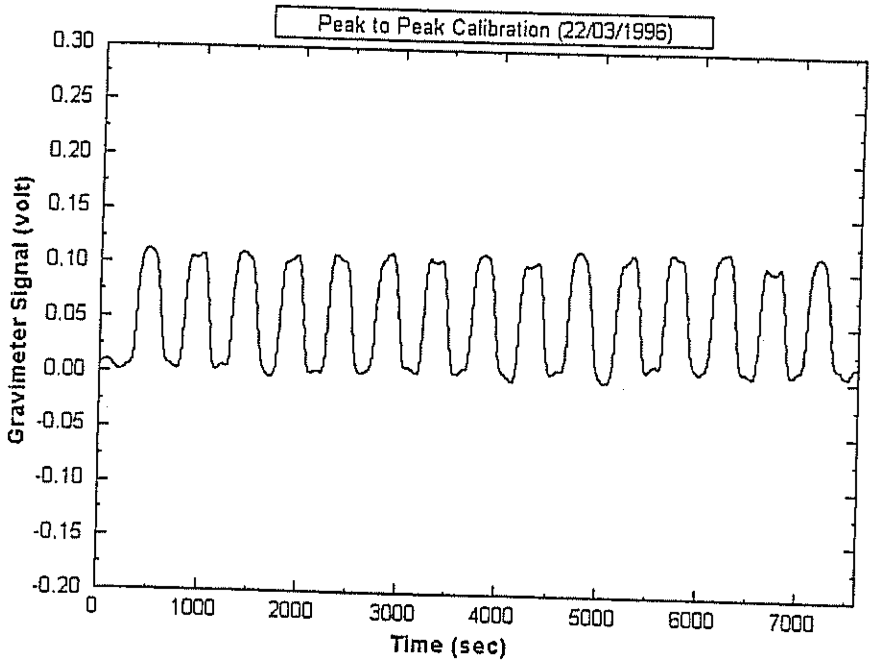

Fig. 3 - Example of peak to peak calibration, the ring is moved from the position of minimum effect to the position of maximum effect in a period of about 8 minutes, and the gravimeter response is recorded.

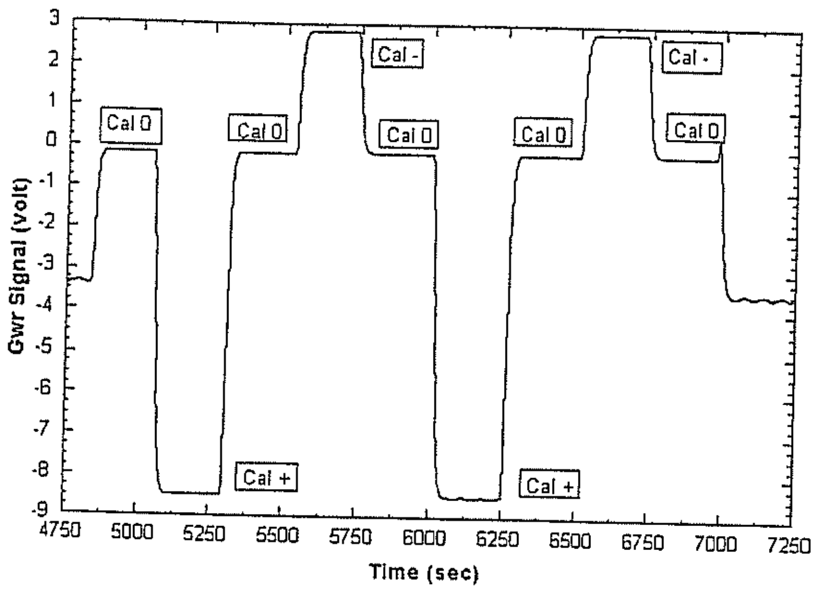

Fig. 4 - Example of electrostatic calibration; a known potential difference of about 5 volt is applied to the capacitance plate of the gravimeter sensor, the response of the gravimeter is recorded and a normalisation factor is computed.

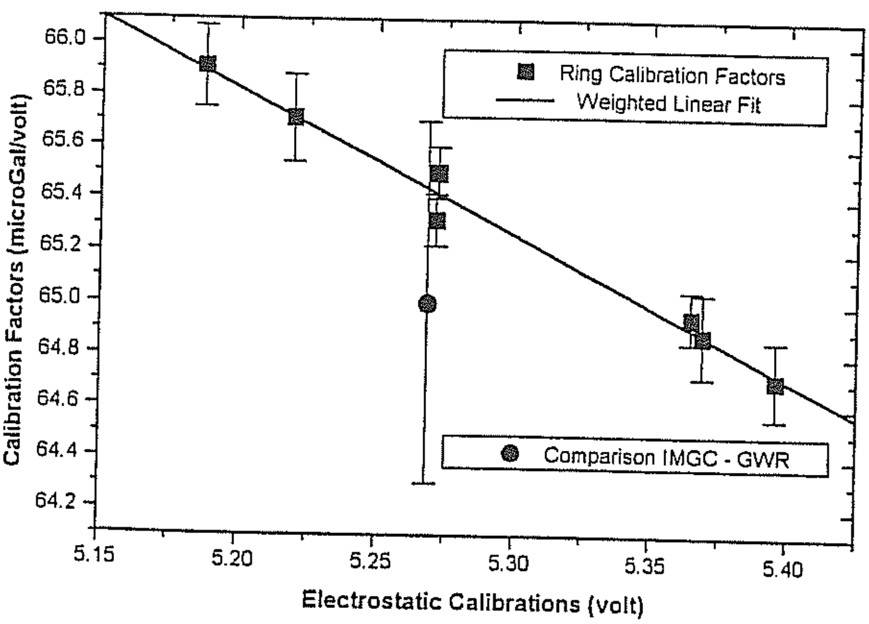

Fig. 5 - Ring calibration factors (squares in the figure) plotted versus the corresponding electrostatic calibrations; a linear trend is observed. Note the value of the calibration obtained from the comparison with the absolute IMGC gravimeter (circle in figure).

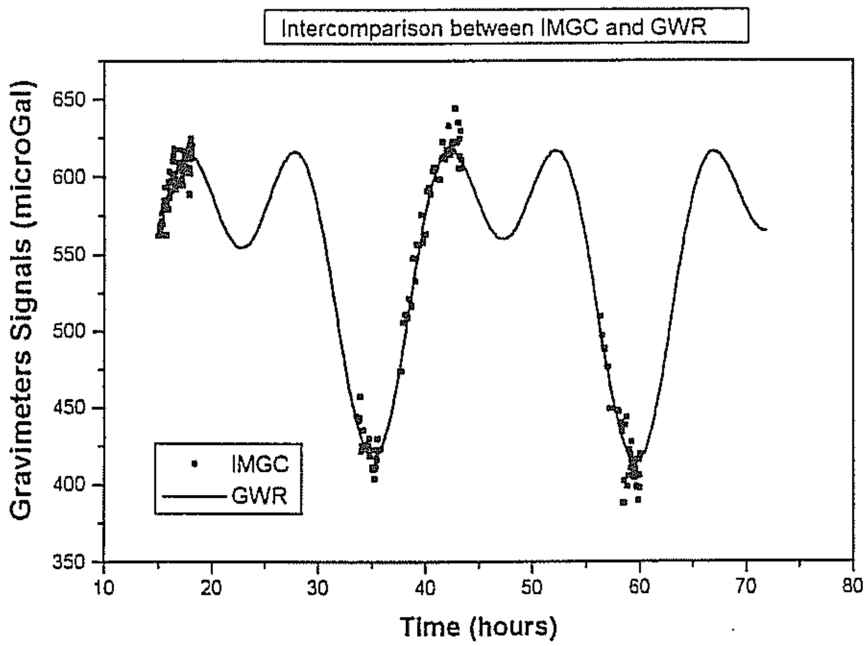

Fig. 6 - Scheme of the calibration for comparison between IMGC absolute and GWR gravimeters; the signal of the superconducting gravimeters (volt) is least square adjusted to the readings of the absolute one (microgal), to calculate the calibration factor of the GWR.

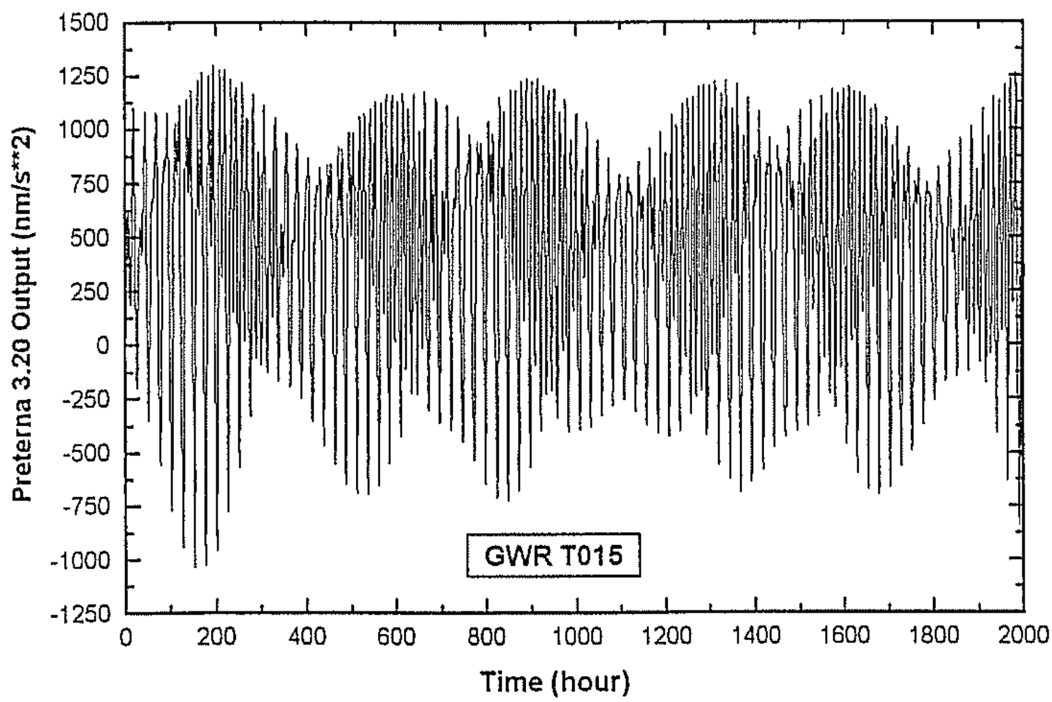

Fig. 7 - Example of data pre-elaborated by means of the Preterna 3.20 program, all spikes, steps and gaps were eliminated at a level of about 3 nm/s^2, the drift was previously corrected using a linear model.

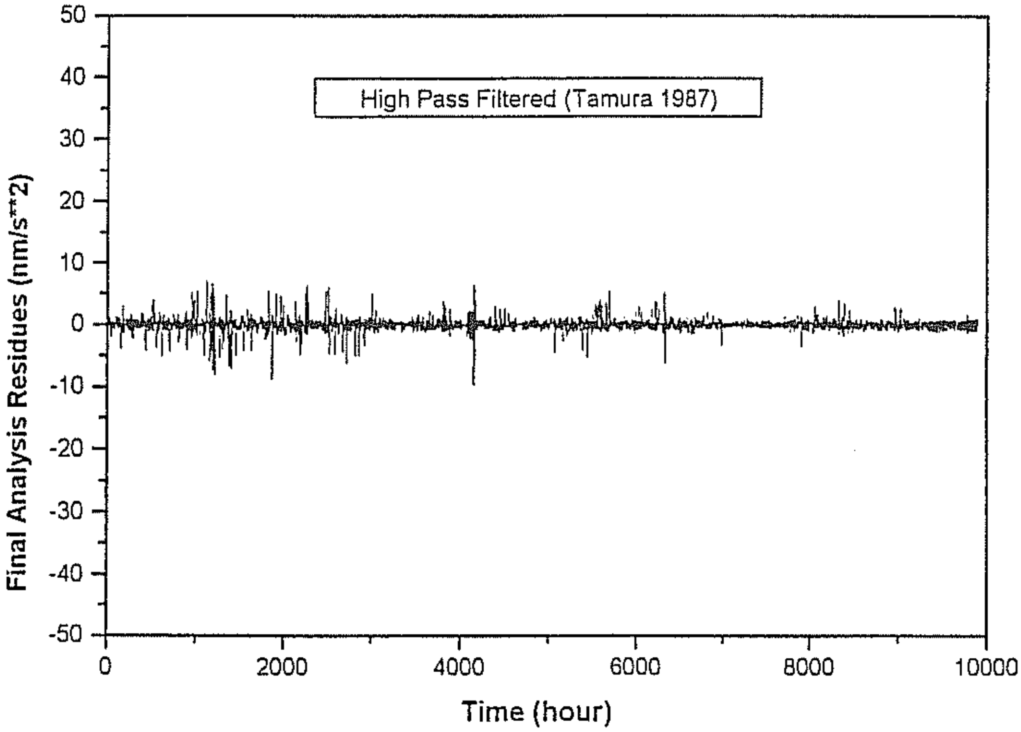

Fig. 8 - Example of HighPass filtered residuals of data analysed with Eterna 3.20 program; a Pertsev number 2 filter was used to reduce atmospheric pressure disturbances.

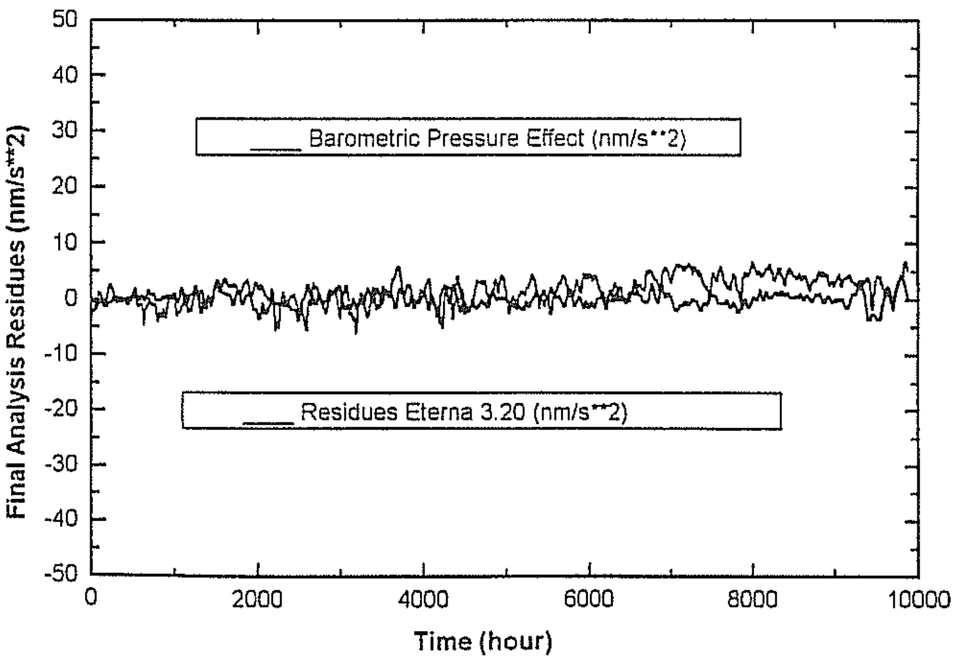

Fig. 9 - Low Pass filtered residuals of a set of 10000 hours of data of the gravimetric station of Brasimone; as can be noted in the figure residuals are still correlated with the barometric pressure.

Period (Year)	Method	Calibration Factors (μgal/volt)	Electrostatic Calibrations (volt)
1991	PSC	65.91 +/- 0.16	5.1875 +/- 0.0009
1992	PSC	65.71 +/- 0.17	5.2198 +/- 0.0003
1993	PSC	65.32 +/- 0.10	5.2715 +/- 0.0003
1994	PSC	65.50 +/- 0.10	5.2722 +/- 0.0003
1995a	PSC	64.95 +/- 0.10	5.3650 +/- 0.0003
1995b	PSC	64.88 +/- 0.18	5.3691 +/- 0.0005
1996	PSC	64.71 +/- 0.15	5.3958 +/- 0.0004

	IMGC Gravimeter		Ring Calibrations	
Date	Drops Number	Calibration Factors (μgal/volt)	Electrostatic Calibration (volt)	Ring Calibration (μgal/volt)
1994-5-9,10,11	166	64.4 +/- 0.5	5.2687 +/- 0.0003	65.26 +/- 0.12
1994-5-10	65	65.0 +/- 0.7		

Tab. I - Results of the ring calibration experiments, of the corresponding electrostatic calibrations and of the calibration for comparison with the IMGC absolute gravimeter.

Tidal Model Computed for the Gravimetric Station of Brasimone Tamura 1987 Catalogue - 1214 Waves					
Wave	Amplitude (nm/s2)	Amplitude Factor δ	RMS	Phase Δϕ (°)	RMS
Ssa	16.363	1.21536	0.23570	2.8103	17.4432
Mm	17.461	1.14251	0.01191	0.7619	0.6864
Mf	33.440	1.15578	0.00646	-0.5506	0.3678
Mtm	6.327	1.14222	0.02033	0.7548	1.1687
Q1	68.814	1.15753	0.00115	-0.2259	0.0660
O1	356.570	1.14837	0.00022	-0.3103	0.0129
M1	28.165	1.15337	0.00251	-0.3155	0.1439
P1	165.854	1.14798	0.00040	-0-1955	0.0229
K1	499.034	1.13263	0.00015	-0.0815	0.0086
J1	28.526	1.16206	0.00292	-0.5713	0.1672
OO1	15.214	1.11290	0.00772	-0.4921	0.4423
2N2	13.715	1.15856	0.00326	0.9383	0.1869
N2	87.185	1.17612	0.00068	1.3003	0.0387
M2	456.727	1.17963	0.00012	0.5827	0.0071
L2	12.766	1.16656	0.00285	-0.2871	0.1634
S2	212.537	1.17988	0.00028	-0.5062	0.0160
K2	57.919	1.18276	0.00133	-0.3076	0.0763
M3	5.815	1.06302	0.00319	-0.1434	0.1828
Residuals Standard Deviation = 2.595 (nm/s2) Barometric Pressure Admit.: $\alpha = -2.712$ +/– 0.005 (nm/s^2*HPa)					
Data availability 01/08/1995 - 30/09/1996					

Table II - Tidal Model Computed from data of the gravimetric station of Brasimone using Eterna 3.20 program. Amplitudes , amplitude factors and phases of the main waves of the tidal catalogue of Tamura 1987 are shown.