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PRECISE INSTRUMENTAL PHASE LAG DETERMINATION BY THE STEP RESPONSE METHOD

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Abstract

The step response method for the determination of the frequency transfer function of a linear sytem with constant parameters, well known in system theory and signal processing, is described in the following with application to the precise determination of the instrumental phase lag of earth tide observation systems. Examples are given for some LaCoste and Romberg gravity meters and one superconducting gravity meter, demonstrating an achievable accuracy of about 1% of the instrumental phase lag's magnitude, corresponding to 0.003^0 ... 0.01^0 for short periodic tidal waves (1 to 4 cpd).

1 Introduction

Recent global earth models (e.g. WAHR 1981, DEHANT 1987, DEHANT and ZSCHAU 1989) based on seismic and free oscillation data predict 0 ... 0.02^0 phase lag corresponding to about 0 ... 2 second time lag for tidal waves at the earth's surface. In principle, phases from earth tide observations could help to verify the global earth models or to constrain the adjustment of these models, if the phases of earth tide observations corrected for ocean loading would be accurate to much better than 0.02^0.

The systematic errors in tidal tilt and strain observations due to e.g. cavity effects do not allow to use these data for the above described purpose. But tidal gravity observations can in principle be used, because their precision is generally much higher and no significant systematic errors due to environmental effects are known in the short periodic tidal band (1 to 4 cpd). In Fig. 1 and Fig. 2 taken from WENZEL, ZÜRN and BAKER 1991 are compared the ocean load corrected phases for O1 and M2 at selected European tidal gravity stations with the predicted values from some recent global earth models. Although the scatter of the phases is about 0.05^0 only and the agreement with the earth models is generally good, the currently available accuracy is not sufficient to prefer one of the global earth models, mainly because of the errors of currently available ocean load corrections.

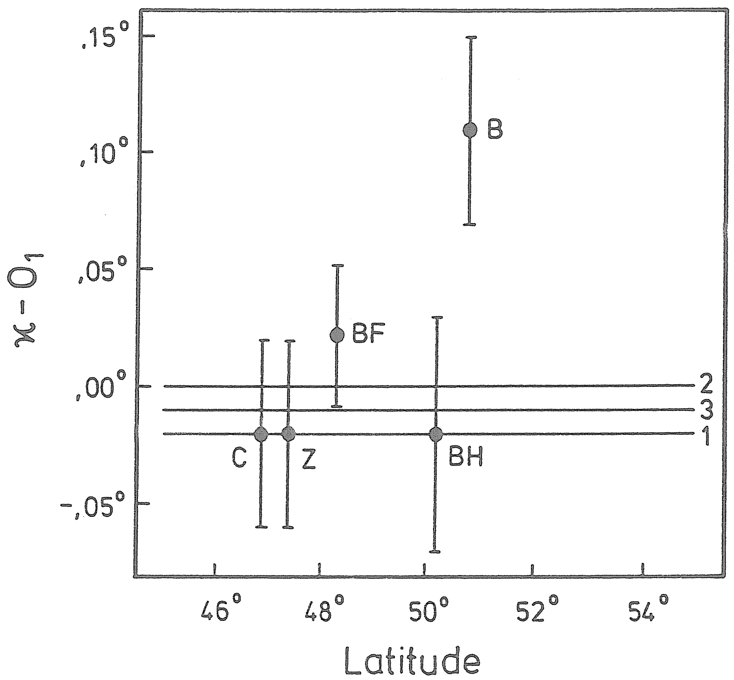

Figure 1: Phases for O1 as a function of latitude for selected European stations (WENZEL, ZÜRN and BAKER 1991). C = Chur, Z = Zürich, BF = BFO Schiltach, BH = Bad Homburg, B = Bruxelles. Solid lines represent earth models : 1 = DEHANT 1987, inelastic, 2 = DEHANT and ZSCHAU 1989, elastic, 3 = DEHANT and ZSCHAU 1989, inelastic.

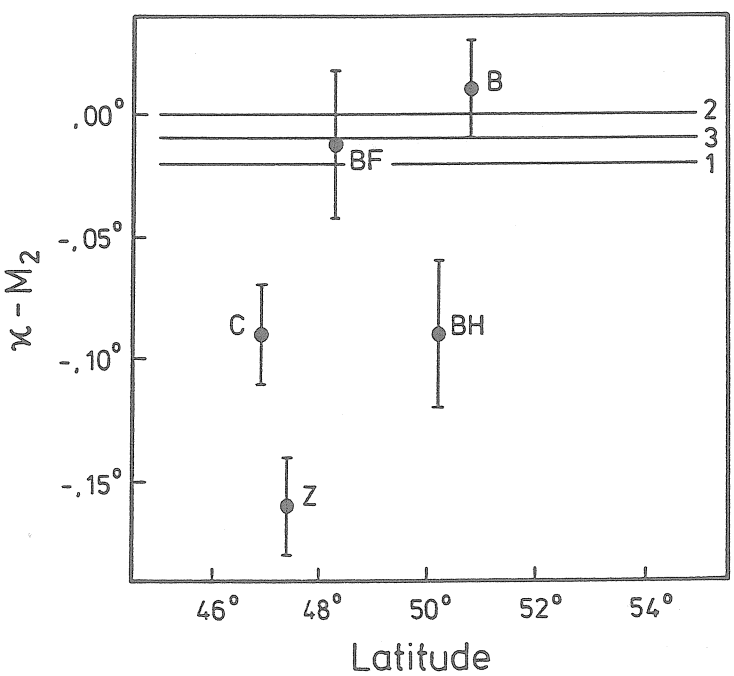

Figure 2: Same as Fig.1 for M2.

The precision of the adjusted phases for the main tidal waves from tidal analysis of precise gravity meter records is about 0.01^0 or less even for short records (some month's length). The phases obtained are influenced from possible clock offsets of the recording system, and the unavoidable instrumental phase lag of the observation system (gravity meter, analog and or numerical filter, recording system). With modern digital recording systems a timing accuracy (sampling time with respect to coordinated universal time) of much below 1 second can easily be achieved. But the instrumental phase lag of the observation system is often not known to that accuracy. Some methods exist for the determination of the instrumental phase lag, which will shortly be discussed within section 2. We will describe in detail the step response method for the precise determination of the instrumental phase lag of earth tide observation systems, which is not new (e.g. WENZEL 1976, BAKER et al. 1981, 1989) but unfortunately not well known by a number of people engaged with earth tide recording. The method is rather general and can be applied to almost any instrument or recording system. A FORTRAN77 programm called ETSTEP for the evaluation of the instrumental phase lag from a recorded step response is described in section 3. Some examples of the application of the step response method are given in section 4 for LaCoste-Romberg gravity meters equipped with electrostatic feedback and for a superconducting gravity meter, demonstrating an accuracy of about 1% for the obtained instrumental phase lags.

Naturally, the limited accuracy of the ocean load corrections due to errors of the currently available ocean tide models (e.g. SCHWIDERSKY 1980) and lateral heterogeneities of the earth's crust under ocean load puts another severe restriction to the use of tidal gravity meters for the verification of recent global earth models. This problem will partly be solved in the near future by currently planned satellite altimeter missions, especially designed for the recovery of ocean tides (TOPEX/POSEIDON mission).

2 Theory

Most of the following theory has been taken from WENZEL 1976; see also textbooks on information theory or signal processing, as e.g. BENDAT and PIERSOL 1971. An ideal observation system (e.g. sensor, filter and recording system) would record the input signal (in our case the earth tide) instantaneously without any distortion :

$$y_{(t)} = x_{(t)} \tag{1}$$

with $x_{(t)}$ = input signal , $y_{(t)}$ = output signal (observation). In fact, an ideal observation system is physically impossible, because any physical observation system needs a certain time to record the input signal (e.g. the mechanical sensor needs some time to react to the force and a subsequent analog filter needs additional time to pass the input signal to the output) and has some small distortions (e.g. non-linearity). Often, a physical observation system consists of a number of different components connected in series (Fig. 3), and each of the components has it's own dynamic characteristic. However, information theory allows the description of the relation between input and output of the observation system (for linear, time invariant and stable systems, see below).

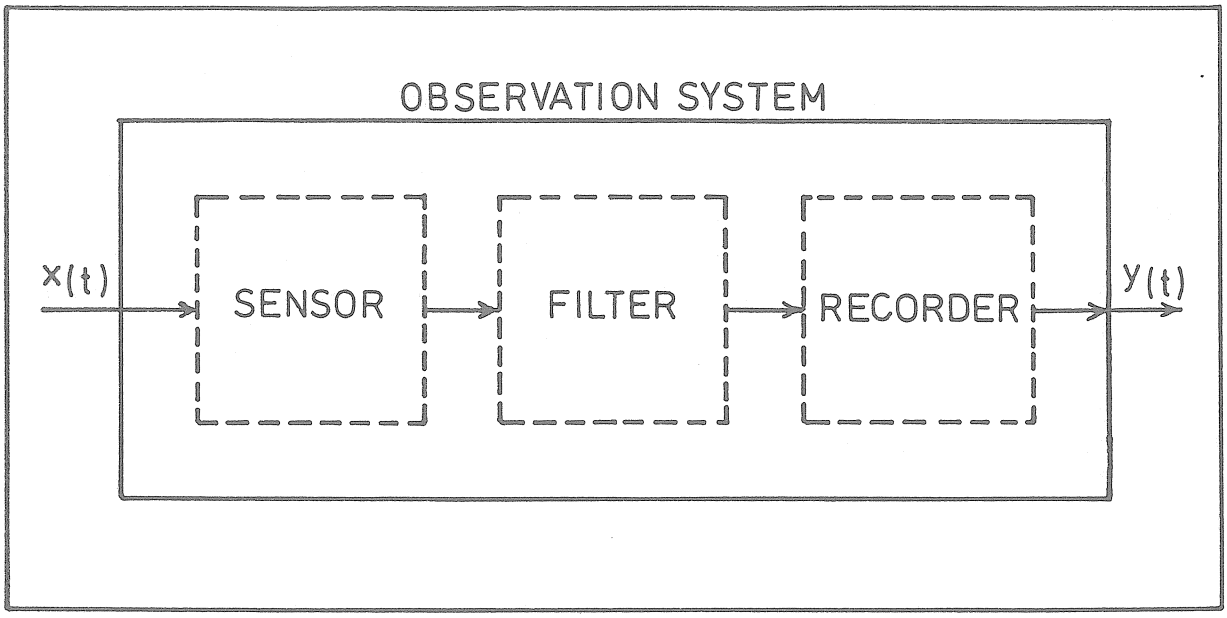

Figure 3: Series connection of physical components form a physical earth tide observation system.

We assume in the following the observation system to be a **linear system with constant parameters**, i.e. the input-output relation can completely be described by

$$y_{(t)} = \int_{\tau=0}^{\infty} h_{(\tau)} \cdot x_{(t-\tau)} d\tau \tag{2}$$

with $h_{(\tau)}$ = weighting function, τ = time lag always greater zero ($h_{(\tau)} = 0$ for $\tau < 0$). The time lag beeing always greater zero means, that the system is **causal**, i.e. not influenced by any future input signal, but only by the past input signal. Because the output depends only on a **linear** combination of $x_{(t-\tau)}$, the system is linear; because the weighting function $h_{(\tau)}$ does not depend on the time t, the system is time invariant, i.e. it has **constant parameters** with respect to time. If the weighting function $h_{(\tau)}$ is absolutely integrable, the output of the system will be bounded and the system is **stable**. Linear systems with constant parameters have some important features, e.g. there does not exist any frequency translation (i.e. an harmonic input signal gives an harmonic output signal at the same frequency), but only modifications of amplitudes and phases of the applied input signal. The model of a linear system with constant parameters is a good approximation for modern earth tide observation systems, e.g. spring gravity meters with a linearized feedback, analog filter and digital recording system. However, some of the older earth tide instruments are known to have severe non-linearities and time varying parameters (as e.g. horizontal pendulums, non-feedback astatized gravity meters, mechanical feedback for LaCoste-Romberg earth tide gravity meters) and the application of the method given below may give incorrect results (the application of those instruments should not be considered for precise earth tide recording).

Complex functions are distinguished in the following by **boldface** typing from real functions. The modification of the **complex spectrum** $\mathbf{X}_{(\omega)}$ of the input signal by the observation system can be described for a linear system with constant parameters by the frequency transform of eq. 2:

$$\mathbf{Y}_{(\omega)} = \mathbf{H}_{(\omega)} \cdot \mathbf{X}_{(\omega)} \tag{3}$$

with $\mathbf{Y}_{(\omega)}$ = **complex spectrum** of the output signal, $\mathbf{H}_{(\omega)}$ = **complex frequency transfer function** of the observation system. The frequency transfer function $\mathbf{H}_{(\omega)}$ is given by

$$\mathbf{H}_{(\omega)} = \int_{\tau=0}^{\infty} h_{(\tau)} \cdot \mathrm{e}^{-\mathrm{j}\omega\tau} d\tau \ . \tag{4}$$

The complex frequency transfer function $\mathbf{H}_{(\omega)}$ can be split into it's real part $p_{(\omega)}$ and it's imaginary part $\mathbf{j} \cdot q_{(\omega)}$ by

$$\mathbf{H}_{(\omega)} = p_{(\omega)} + \mathbf{j} \cdot q_{(\omega)} \ . \tag{5}$$

An earth tide recording system usually consists of a number of different components connected in series (e.g. mechanical sensor with electronic transducer and feedback system, analog filter, digital recording system, see Fig. 3). Each of the components can be described by it's own frequency transfer function $\mathbf{H}_{\mathbf{i}_{(\omega)}}$, which usually is not known (except for the analog filter, where the frequency transfer function can be computed from the electrical circuit). The frequency transfer function of the complete observation system is given by the product of all individual frequency transfer functions

$$\mathbf{H}_{(\omega)} = \prod_{i=1}^{n} \mathbf{H}_{\mathbf{i}_{(\omega)}} \tag{6}$$

and only the frequency transfer function $\mathbf{H}_{(\omega)}$ of the **complete observation system** need to be determined usually.

The frequency transfer function $\mathbf{H}_{(\omega)}$ of an earth tide observation system has generally the characteristics of a low pass filter, i.e. long periodic signals pass the observation system with only small modifications, whereas short periodic signals (i.e. with periods in the order of seconds) are heavily damped. This is mainly because of the suppression of microseismic noise due to e.g. slow feedback response or an analog low pass filter applied to the sensor signal in order to prevent aliasing.

The **amplitudes** evaluated from the recording of the observation system have to be corrected because of the **frequency dependent gain** of the observation system $G_{(\omega)}$:

$$A_{y_{(\omega)}} = G_{(\omega)} \cdot A_{x_{(\omega)}} \tag{7}$$

with

$$G_{(\omega)} = \sqrt{p_{(\omega)}^2 + q_{(\omega)}^2} \tag{8}$$

and $A_{x_{(\omega)}}$ = amplitude of the input signal, $A_{y_{(\omega)}}$ = amplitude of the output signal. It will be shown in section 4, that the gain of modern gravimetric earth tide observation systems is constant over a large frequency range. The determination of the system's gain for zero frequency is usually done by a calibration procedure and will not be considered in the following. The **phases** evaluated from the recording of the observation system have to be corrected because of the **frequency dependent phase lag** $\psi_{(\omega)}$ of the observation system :

$$\varphi_{y_{(\omega)}} = \varphi_{x_{(\omega)}} - \psi_{(\omega)} \tag{9}$$

with

$$\psi_{(\omega)} = \arctan \frac{q_{(\omega)}}{p_{(\omega)}} \tag{10}$$

and φ_x = phase of the input signal with respect to t = 0, φ_y = phase of the output signal with respect to t = 0. For a number of linear systems with constant parameters, the phase lag $\psi_{(\omega)}$ increases almost linear with the frequency; therefore the phase delay time $\theta_{(\omega)}$ (in the following simply denoted as time lag)

$$\theta_{(\omega)} = \psi_{(\omega)} \cdot T \tag{11}$$

with T = period, is almost constant for those systems over the frequency range of interest for earth tide observations.

The determination of the frequency dependent phase lag $\psi_{(\omega)}$ is the subject of this paper; it will be shown in section 4, that the phase lags of modern gravimetric earth tide observation systems can amount up to about 1^0 and therefore have to be determined with an accuracy of much better than 1% for the purpose described in section 1.

Different methods exist for the determination of the frequency transfer function of observation systems, which all apply a well known signal to the systems's input and analyse the observed system's response to the input signal. As input signal

- a sine wave with known amplitude, phase and known frequency can be supplied to the input of the observation system, and the output signal of the system can be observed. By doing this for a number of different frequencies, the frequency transfer function of the observation system can be derived by comparison of the input and output amplitudes and phases (e.g. STUKENBRÖCKER 1971, DUCARME 1975). This method is implicitely applied when using an inertial platform for the calibration of earth tide gravity meters (e.g. VALLIANT 1973, RICHTER 1987, VAN RUYMBEKE 1989), although it is mainly used for the determination of the system's gain.

- a pseudo random signal with known characteristics can be supplied to the input of the observation system. By computing the cross spectrum between the input signal and the output signal of the system, the frequency transfer function of the observation system is obtained. The method is rather complicated and can only be applied for instruments with electrostatic or electromagnetic force input resp. feedback. This method has been used extensively for gravity meters operating as long periodic seismometers in the global IDA free oscillation network (e.g. BERGER et al. 1979).

- a step function at known time can be input and the step response of the observation system can be observed and analysed (Fig. 4); this method is available for almost any earth tide instrument by using e.g. the available reset screw, an electrostatic or electromagnetic force (e.g. WENZEL 1976, FARREL and BERGER 1979, BAKER et al. 1981, 1989, RASSON and DE MEYER 1983, 1986). Calibration steps, often applied for earth tide observation systems, can be used for the step response method, provided the data recording is carried out with a suffient high sampling rate.

- the earth tides can be used in a reference station (so called fundamental station), provided the tidal phases are known with a very high accuracy at the reference station (i.e. the instrumental phase lags of the instruments used for the determination of the tidal phases at the reference station have been determined by other methods). This concept has extensively used by the International Earth Tide Centre at Bruxelles for the instrumental phase lag determination of a number of gravity meters, installed for earth tide recording at a number of stations globally distributed. The comparison recording at a reference station has several disadvantages, which are the limited accuracy of the tidal phases at the reference station and possible time variations of the tidal phases due to e.g. time variable ocean loading effects, the limited accuracy of the tidal phases obtained during the comparison recording, the long time span necessary for the comparison recording, and the possible time variability of the system's phase lag during transportation to or setup in a far away station, especially for non-feedback astatized gravity meters.

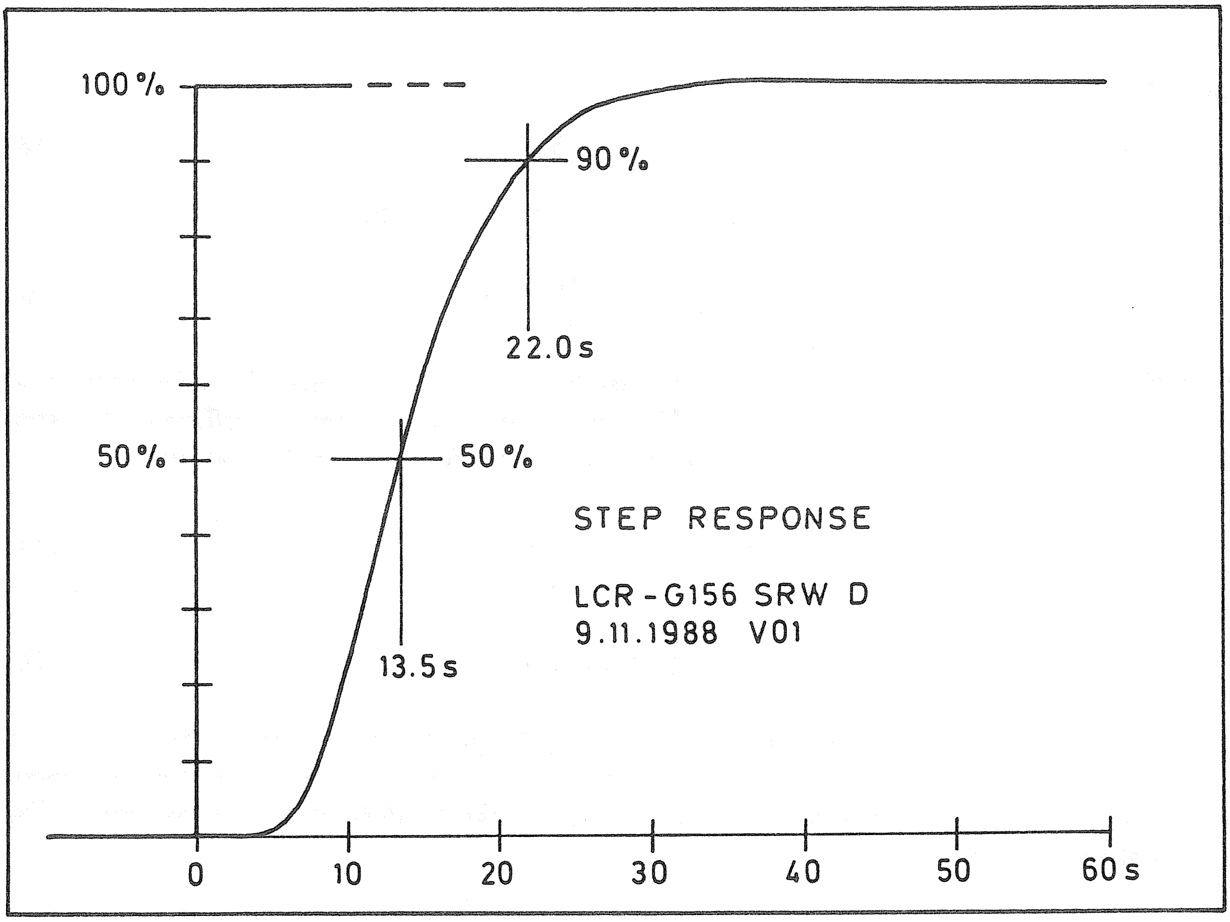

Figure 4: Step function and step response for gravity meter LCR-G156F with electrostatic feedback SRW, recorded 881109 at Karlsruhe, experiment ST156V01.

We will in the following restrict ourselves to the step response method, because it has the advantage of broadest application possibility. A number of attempts have been made to model the dynamic behavior of the observation system from the observed step response (e.g. VOLKOV and PARIISKY 1974, DUCARME 1975, FARREL and BERGER 1979). This procedure can give reliable results, if the physics of the observation system is clearly understood and the dynamic characteristic is well approximated by the parametric model (see section 4). The adjustment of simple exponential functions to the observed step response (e.g. VOLKOV and PARIISKY 1974, DUCARME 1975) may lead to incorrect results, because the dynamic characteristics of modern earth tide observation systems can in most cases not be approximated by such a simple model (e.g. the step response of a high order analog Butterworth low pass filter has significant overshooting, and cannot be modeled by a combination of simple exponential functions). The derivation of the frequency transfer function from the differentiated step response described in the following does not explicitely use any parametric model of the observation system and can be applied to almost any observation system, provided it is a stable linear system with constant parameters.

If we apply a step function to the input of the observation system

$$x_{(t)} = \begin{cases} 0 & \text{for } t < t_0 \\ C & \text{for } t \geq t_0 \end{cases} \tag{12}$$

then (2) reads as

$$y_{(t)} = C \cdot \int_{\tau=0}^{t-t_0} h_{(\tau)} d\tau \tag{13}$$

and by differentiation of (13) the weighting function $h_{(\tau)}$ is obtained by:

$$h_{(\tau)} = \frac{1}{C} \cdot \frac{dy}{dt} \ . \tag{14}$$

The differentiation of the recorded step response has usually to be carried out by numerical methods. The frequency transfer function $\mathrm{H}_{(\omega)}$ can be computed from the differentiated step response by Fourier transformation, e.g. using a discrete Fourier transformation :

$$p_{(\omega)} = \frac{1}{n} \sum_{i=1}^{n} h_{(\tau_i)} \cdot \cos \omega \tau_i \ , \tag{15}$$

$$q_{(\omega)} = \frac{1}{n} \sum_{i=1}^{n} h_{(\tau_i)} \cdot \sin \omega \tau_i \ . \tag{16}$$

Unfortunately, the step response method does not give any error estimation, because it is a pure deterministic one and not based on statistical principles. But a number of step responses can be observed and analysed and error estimates can be derived by comparison of the individual results (see section 4).

The step response method suffers from the fact, that the input signal to the observation system is never a pure step function; each physical system used to generate the step function has it's own frequency transfer function (e.g. the generation of a step by using the gravimeters screw is not a step but almost a ramp with time). Because the generated step function should be as close as possible to a mathematical one, the generation of a step function by a quick electrical signal should always be preferred. Some of the electronic feedback systems have an additional input parallel to the feedback voltage in order to generate a step force to the mechanical sensor.

Additionally, the earth tide observation system naturally reacts in addition to the input step to time variation of the physical variable to be observed (e.g. the gravity variation, microseismic noise) and has some own slow time variation (e.g. drift of the sensor). In order to suppress the disturbing signals for the step response, the step function should have an amplitude as large as possible (but naturally this is limited by the range of the sensor and subsequent components). If possible, the step experiments should be carried out, when the tidal gravity variation is small and flat. Additionally, step functions with different signs should be applied in order to compensate the effects of slow variation of the input signal and the sensor's drift.

Finally, it should be mentioned, that the step response method can also be applied to the determination of the frequency transfer function of other channels connected to an earth tide instrument, as e.g. a free mode channel.

3 Evaluation of the Recorded Step Response

For the evaluation of the frequency transfer function of an observation system from a recorded step response, a FORTRAN 77 program called ETSTEP has been written. The program reads the observed step response (not necessarily equidistant with time) at a number of samples (at maximum 1500) and normalizes the step response to zero at the first sample (time of the step) and to unity at the last recorded sample (this can only be applied for a low pass type observation system). The differentiation of the recorded step response is carried out by fitting at a number of equidistant time points a moving third degree least squares polynomial (maximum degree is 10) to a selectable number of samples (greater 4, at maximum 20). A least squares polynomial is used in order to smooth the noise in the recorded step response. The differentiated step response is directly computed from the polynomial coefficients, and the frequency transfer function is subsequently computed by discrete Fourier transformation. The frequency transfer function (real part, imaginary part, gain, phase lag and time lag) is evaluated at a number of frequencies from zero to 0.9 cps and for the main tidal waves. If no sample data are input to the program, the program carries out a program test by internally generating the step response for a 10 s RC low pass filter and compares the frequency transfer function numerically derived from the step response with the analytically computed frequency transfer function of the RC filter. The program ETSTEP operates on an IBM-AT personal computer under operation system MS-DOS 3.3 upwards and is available on request by the authors.

4 Step Response Experiments

4.1 Description of Experiments

Some of the step response experiments discussed in the following have been carried out in course of a parallel earth tide recording experiment for the calibration of the stationary LaCoste-Romberg (LCR) earth tide gravity meter ET19 equipped with a WEBER-LARSON electrostatic feedback, and LCR-G156F and LCR-G249F equipped with an SRW electrostatic feedback (e.g. SCHNÜLL et al. 1984) in 1988/1989 at BFO Schiltach (WENZEL, ZÜRN and BAKER 1991). Another parallel earth tide recording experiment has been carried out at station Strasbourg in 1990 for the calibration of superconducting gravity meter TT70, using the gravity meters LCR-G156F and LCR-G249F with the same equipment as before. The instrumental phase lags for the LCR gravity meters have been determined by the step response method either in routine performance check (LCR-ET19) or during the preparation or setup of the instruments for the parallel recording experiments. The following step response experiments are discussed below in detail :

- **STET1901** step response of LCR-ET19 feedback buffered tide output by voltage step in parallel adder to the feedback, recorded 860712 at BFO Schiltach. Analog recording of the step response for 50 s with 0.4 mm/s recording speed. Sample rate 2.5 s.
- **STBW3V01** step response of 8th order 150 s Butterworth antialias filter no. 3, recorded 900912 at Karlsruhe. Step by 2.2 V voltage step at the filter's input. Analog recording of the step response for 1200 s with 0.17 mm/s recording speed. Sample rate 10 s.
- **STBW3V02** same as STBW3V01, but different step direction.
- **STBW4V01** same as STBW3V01, for 8th order 150 s Butterworth antialias filter no. 4. Both filters have an identical electrical circuit, but slightly different electrical components due to tolerances.
- **STBW4V02** same as STBW4V01, but different step direction.
- **ST156V01** step response of LCR-G156F electronic feedback SRW recorded 881109 at Karlsruhe. Step by quick turn of the gravity meter's micrometer screw of about 8 $\mu m/s^2$. Analog recording of the step response for 90 s with 2 mm/s recording speed and about 50 nm/s^2 per mm sensitivity. Sample rate 1 sec. The recorded step response is given exemplarily in Fig. 4.
- **ST156V02** same as ST156V01, but different step direction.
- **ST156V03** step response of LCR-G156F electronic feedback SRW with 150 s 8th order Butterworth antialias filter no. 1 in series recorded 890413 at BFO Schiltach. The 150 s antialias filter was applied because of the low sample rate used in the digital recording of the parallel earth tide recording experiment. Step by quick turn of the gravity meter's micrometer screw of about 7 $\mu m/s^2$. Analog recording of the step response for 900 s with 30 mm/s recording speed and about 50 nm/s^2 per mm sensitivity. Sample rate 10 s.
- **ST156V04** same as ST156V03, but different step direction.
- **ST156V05** same as ST156V03, but recorded 900711 at Karlsruhe.
- **ST156V06** same as ST156V05, but different step direction.
- **ST249V01** same as ST156V01 for gravimeter LCR-G249F.
- **ST249V02** same as ST249V01, but different step direction.
- **ST249V03** same as ST156V03 for gravimeter LCR-G249F and 150 s 8th order Butterworth antialias filter no. 2.
- **ST249V04** same as ST249V03, but different step direction.
- **ST249V05** same as ST249V03, but recorded 900711 at Karlsruhe.
- **ST249V06** same as ST249V05, but different step direction.

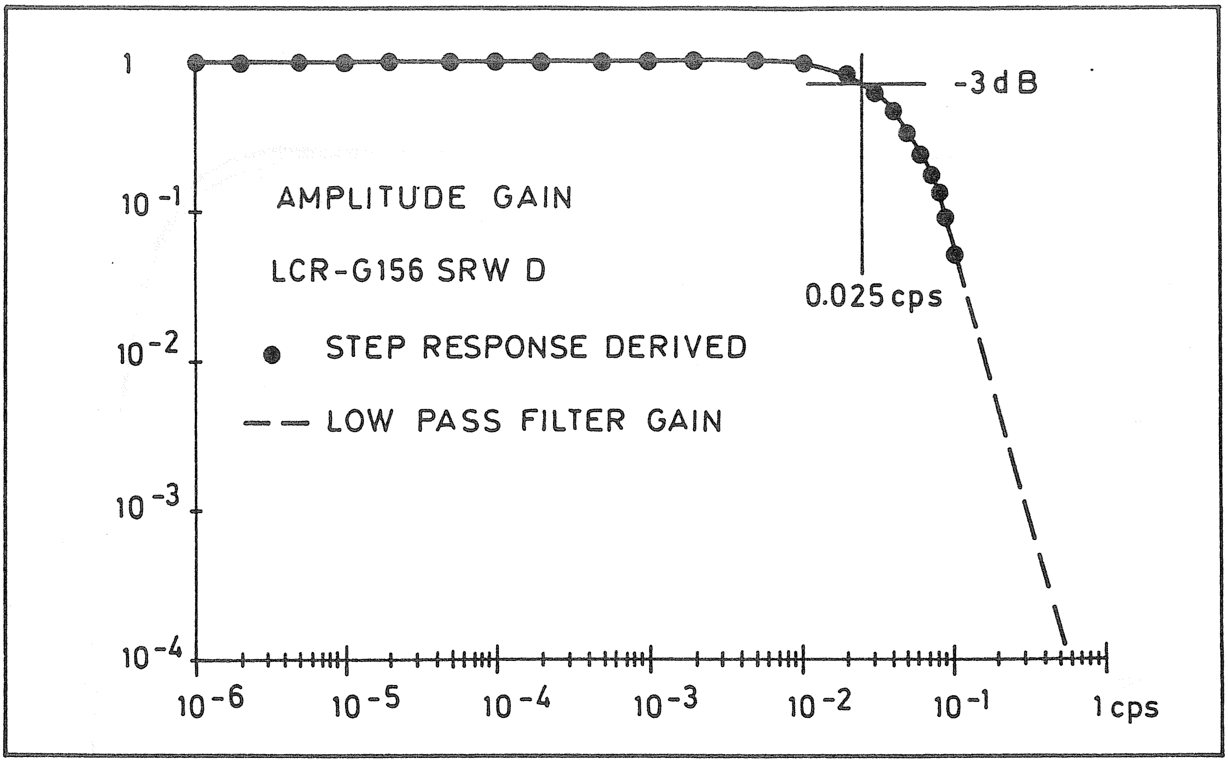

Figure 5: Gain function for gravity meter LCR-G156F with electrostatic feedback SRW, recorded 881109 at Karlsruhe, experiment ST156V01.

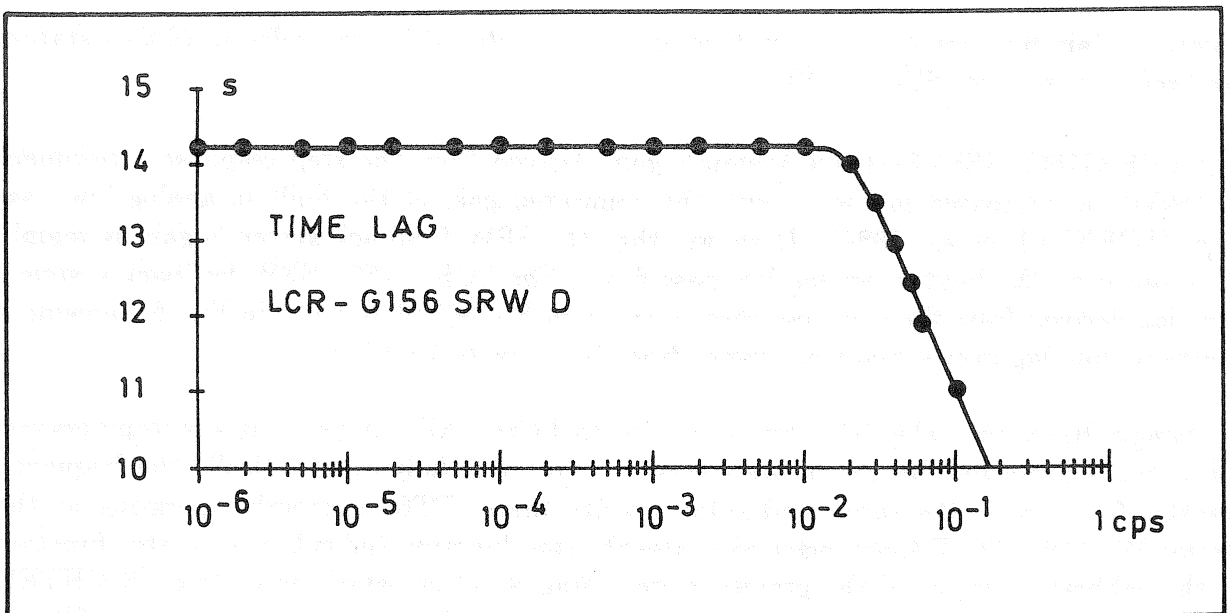

Figure 6: Time lag function for gravity meter LCR-G156F with electrostatic feedback SRW, recorded 881109 at Karlsruhe, experiment ST156V01.

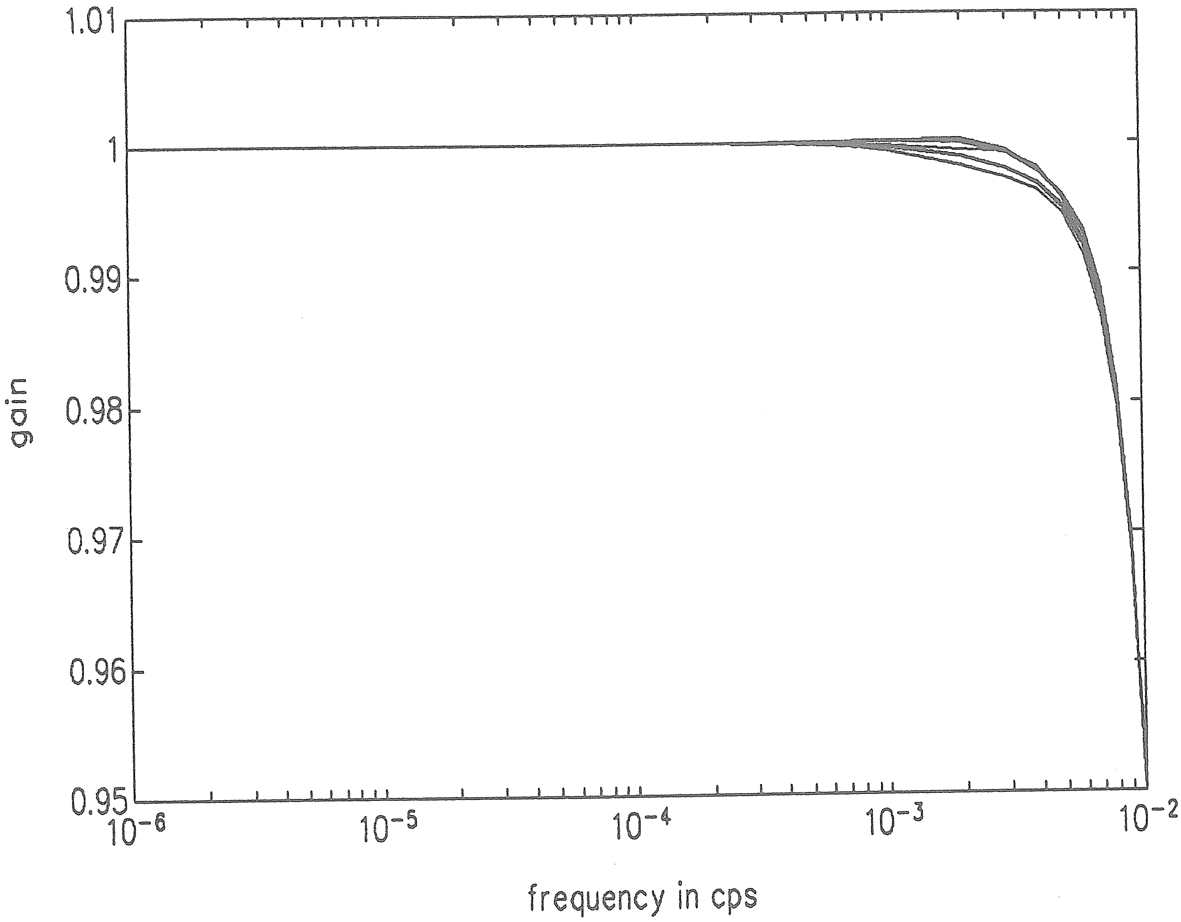

Figure 7: Gain function for superconducting gravity meter TT60, recorded in 1990 at station Wettzell, experiments SFU1 ... SFU7.

The LCR-G156F SRW feedback system's gain derived from the step response experiment ST156V01 is compared in Fig. 5 with the computed gain of the built in analog low pass filter (SCHNÜLL et al. 1984). It shows, that the SRW feedback system's gain is mainly determined by the built in analog low pass filter. The LCR-G156F SRW feedback system's time lag derived from the step response experiment ST156V01 is given in Fig. 6, showing a constant time lag over a frequency range from 10^{-6} cps to 10^{-2} cps.

By using a digital to analog (DA) and an analog to digital (AD) converter in a laptop personal computer, a procedure has been established to determine fully automatically the frequency transfer function of the superconducting gravity meter TT60 currently operating at the station Wettzell. The DA converter generates the step function and submits the step function to the calibration input of the gravity meter using an electrostatic force (e.g. RICHTER 1987), and the DA converter records the step response of the gravity meter's tide filtered output channel. The evaluation of the step response is subsequently done by the computer automatically. Because of the automatized procedure, a number of step response experiments can be carried out with reasonable effort. The following experiments are discussed in detail below :

- **SFU1** step response of superconducting gravity meter TT60 tide filter channel due to voltage step 0 V to +8 V into the calibration input, recorded in 1990 at station Wettzell. Digital recording of the step response for 300 s with 1 s sample rate, resolution 10 μV. Output step is about 3.0 V.
- **SFU2** same as SFU1, with voltage step +8 V to 0 V.
- **SFU3** same as SFU1, with voltage step 0 V to +8 V.
- **SFU4** same as SFU1, with voltage step -8 V to +8 V.
- **SFU5** same as SFU1, with voltage step +8 V to 0 V.
- **SFU6** same as SFU1, with voltage step 0 V to +8 V.
- **SFU7** same as SFU1, with voltage step +8 V to 0 V.

The system's gain of superconducting gravity meter TT60 is shown in Fig. 7, and it's instrumental phase lag is shown in Fig. 8.

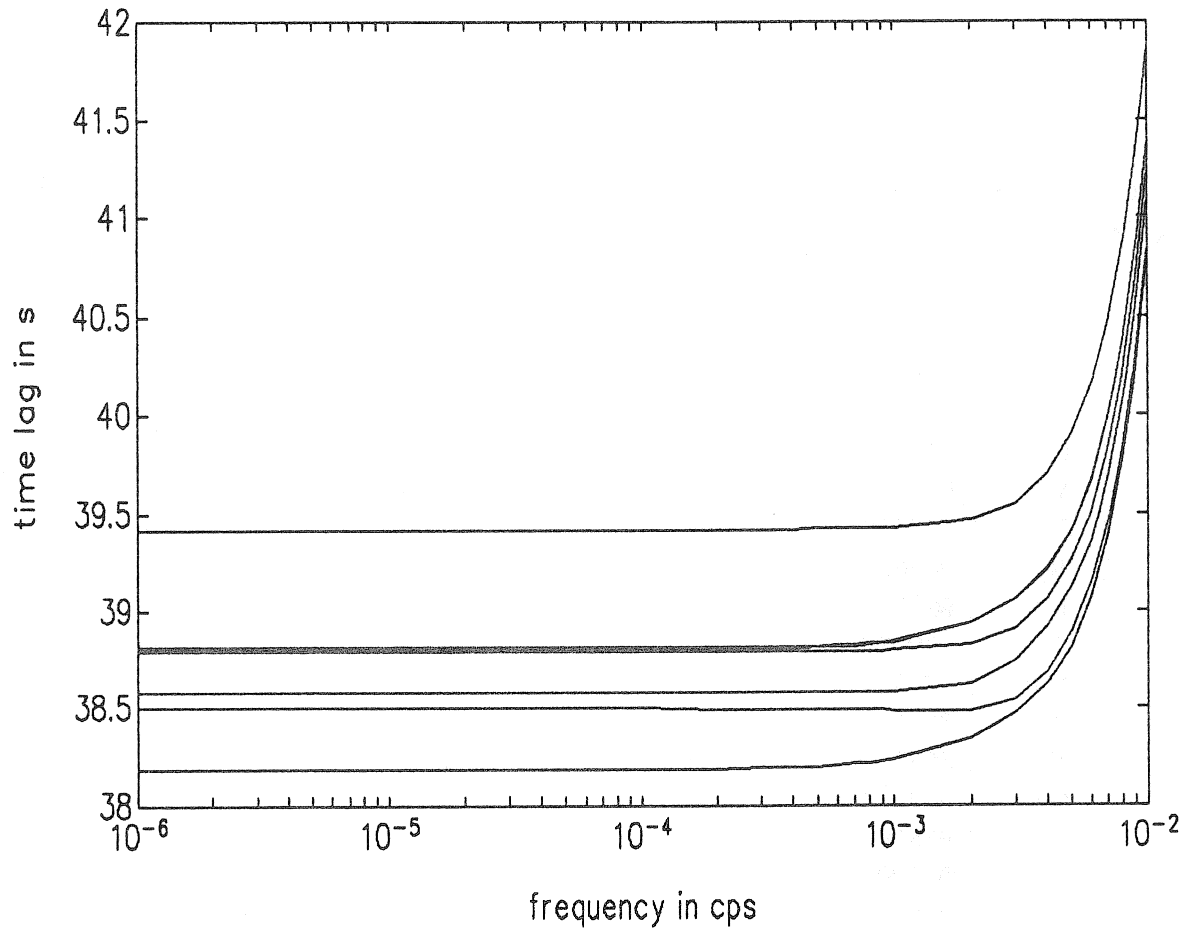

Figure 8: Instrumental time lag for superconducting gravity meter TT60, recorded in 1990 at station Wettzell, experiments SFU1 ... SFU7.

4.2 Validation of the Step Response Method

From the step response experiment STET1901, W. Zürn (BFO Schiltach) has derived a parametric model for the mechanical sensor and the electrostatic feedback of gravity meter ET19 by an iterative method (computation of the step response from the parametric model by Laplace transformation and comparison with the observed step response). The parametric model of the frequency transfer function of the LCR-ET19 mechanical sensor and electronic feedback is (W. Zürn, personal communication)

$$H_{(\omega)} = C \cdot \frac{1}{\prod_{i=1}^{3}(j\omega - \eta_i)} \qquad (17)$$

with C = 4.81243 $\cdot 10^3$ $[V \cdot (ms^{-2})^{-1} \cdot s^{-3}]$, η_1 = -0.0800 s^{-1} + j$\cdot$ 0.250 s^{-1}, η_2 = -0.0800 s^{-1} - j$\cdot$ 0.250 s^{-1}, η_3 = -0.1020 s^{-1}. The instrumental phase lag computed from the parametric model is compared in Tab. 1 for the main tidal waves with the instrumental phase lag computed from Fourier transform of the differentiated step response. The discrepancies between the two different methods applied to the same step response experiment reach at maximum 0.001^0, demonstrating a precision of the Fourier transform of the differentiated step response of better 1%.

Table 1: Comparison of Instrumental Phase Lags from Step Response Experiment STET1901 Using a Parametric Model and Fourier Transform of the Differentiated Step Response.

wave (1)	frequency (2) [cpd]	Fourier transform (3) [°]	parametric model (4) [°]	diff. (4)-(3) [°]
Q1	0.893244	0.045	0.045	0.000
O1	0.929536	0.046	0.047	0.001
M1	0.966446	0.048	0.049	0.001
P1	0.997262	0.050	0.050	0.000
S1	1.000000	0.050	0.050	0.000
K1	1.002738	0.050	0.051	0.001
J1	1.039030	0.052	0.052	0.000
OO1	1.075940	0.054	0.054	0.000
2N2	1.864547	0.093	0.094	0.001
N2	1.895982	0.095	0.096	0.001
M2	1.932274	0.097	0.098	0.001
L2	1.968565	0.098	0.099	0.001
S2	2.000000	0.100	0.101	0.001
K2	2.005476	0.100	0.101	0.001
M3	2.898410	0.145	0.146	0.001

Table 2: Comparison of Instrumental Phase Lags from Step Response Experiments STBW3V01 and STBW3V02 with the Computed Antialias Filter Phase Lag.

wave (1)	frequency (2) [cpd]	STBW3V01 (3) [^{0}]	STBW3V02 (4) [^{0}]	average (5) [^{0}]	filter (6) [^{0}]	diff. (6)-(5)] [^{0}]
Q1	0.893244	0.463	0.458	0.460	0.455	-0.005
O1	0.929536	0.481	0.477	0.479	0.474	-0.005
M1	0.966446	0.501	0.496	0.498	0.493	-0.005
P1	0.997262	0.516	0.511	0.514	0.508	-0.006
S1	1.000000	0.518	0.513	0.516	0.510	-0.006
K1	1.002738	0.519	0.514	0.516	0.511	-0.005
J1	1.039030	0.538	0.533	0.536	0.530	-0.006
OO1	1.075940	0.557	0.552	0.554	0.548	-0.006
2N2	1.864547	0.966	0.956	0.961	0.951	-0.010
N2	1.895982	0.982	0.972	0.977	0.967	-0.010
M2	1.932274	1.001	0.991	0.996	0.985	-0.011
L2	1.968565	1.020	1.010	1.015	1.004	-0.011
S2	2.000000	1.036	1.026	1.031	1.020	-0.011
K2	2.005476	1.039	1.029	1.034	1.022	-0.012
M3	2.898410	1.501	1.486	1.494	1.478	-0.016

Table 3: Comparison of Instrumental Phase Lags from Step Response Experiments STBW4V01 and STBW4V02 with the Computed Antialias Filter Phase Lag.

wave (1)	frequency (2) [cpd]	STBW4V01 (3) [^{0}]	STBW4V02 (4) [^{0}]	average (5) [^{0}]	filter (6) [^{0}]	diff. (6)-(5)] [^{0}]
Q1	0.893244	0.462	0.455	0.458	0.455	-0.003
O1	0.929536	0.480	0.473	0.476	0.474	-0.002
M1	0.966446	0.499	0.492	0.496	0.493	-0.003
P1	0.997262	0.515	0.507	0.511	0.508	-0.003
S1	1.000000	0.517	0.509	0.513	0.510	-0.003
K1	1.002738	0.518	0.510	0.514	0.511	-0.004
J1	1.039030	0.537	0.529	0.533	0.530	-0.003
OO1	1.075940	0.556	0.547	0.552	0.548	-0.004
2N2	1.864547	0.964	0.949	0.956	0.951	-0.005
N2	1.895982	0.980	0.965	0.972	0.967	-0.005
M2	1.932274	0.999	0.983	0.991	0.985	-0.006
L2	1.968565	1.017	1.002	1.010	1.004	-0.006
S2	2.000000	1.034	1.018	1.026	1.020	-0.006
K2	2.005476	1.036	1.020	1.028	1.022	-0.006
M3	2.898410	1.498	1.475	1.486	1.478	-0.008

With step response experiments STBW3V01, STBW3V02, STBW4V01 and STBW4V02, the phase lags of two 8th order 150 s Butterworth antialias filters have been determined experimentally. The phase lag of the filters can independently be computed from the electrical circuit (e.g. TIETZE and SCHENK 1988) with an accuracy of about 1% (because of tolerances of the electrical components). The comparison of the filter's phase lag determined by the step response with the computed phase lag from the electrical circuit is given in Tab. 2 and Tab. 3. The repeated step response experiments agree within 0.01^0 for semidiurnal waves, and the discrepancies between the step response derived and from the electrical circuit computed phase lags are within 0.01^0 for the semidiurnal tidal waves. This is in agreement with the estimated accuracy of the phase lags computed from the electrical circuit, demonstrating an external accuracy of the step response method in the order of 0.01^0 for the semidiurnal waves, corresponding to about 1% accuracy of the step response derived instrumental phase lag.

4.3 Precision Estimation for Step Response Experiments

The results of step response experiments ST156V01, ST156V02, ST249V01 and ST249V02 are compared in Tab. 4 and Tab. 5 for the main tidal waves with the computed phase lag of the built in low pass filter. The internal agreement of the step response experiments is in the order of 0.003 ^{0} for the semidiurnal waves. The difference to the computed filter phase lag gives an estimate of the phase lag of the gravity meter's mechanical sensor and SRW proportional-integral feedback in the order of 0.01^0 for semidiurnal waves.

The results of step response experiments ST156V03, ST156V04, ST156V05, ST156V06, ST249V03, ST249V04, ST249V05, and ST249V06 are compared in Tab. 6 and Tab. 7 for the main tidal waves. The internal agreement for these experiments in the order of 0.03^0 for the instrumental phase lag of semidiurnal waves is worse than for experiments ST156V01, ST156V02, ST249V01 and ST249V02. This is assumed to be mainly related to slow signal variations during the longer time span for which the step response was recorded. The second set of experiments (V05/V06) has been recorded more than one year later than the first set (V03/V04). During that time span, the gain of the capacitive position indicator of LCR-G249F has been changed, causing a significant change of the feeback's phase lag. The differences between the results from the two sets of experiments amount to about 0.01^0 for LCR-G156F and to about 0.04^0 for LCR-G249F at semidiurnal tides and are in the same order as the precision of a single step response experiment.

The results of the seven step response experiments SFU1 ... SFU7 with the superconducting gravity meter TT60 are compared in Tab. 8, showing a standard deviation of 0.002^0 ... 0.003^0 for a single step response experiment. The average of the estimated time lags of the system (minimum value of 38.18 s, maximum value of 39.42 s) is 38.73 $\pm$ 0.14 s.

Table 4: Comparison of Instrumental Phase Lag from Step Response Experiments ST156V01 and ST156V02 with the Phase Lag of the SRW Built in Analog Filter.

wave (1)	frequency (2) [cpd]	ST156V01 (3) [°]	ST156V02 (4) [°]	diff. (4)-(3) [°]	average (6) [°]	filter (7) [°]	diff. (6)-(7) [°]
Q1	0.893244	0.053	0.055	0.002	0.054	0.049	0.005
O1	0.929536	0.055	0.057	0.002	0.056	0.051	0.005
M1	0.966446	0.057	0.059	0.002	0.058	0.053	0.005
P1	0.997262	0.059	0.061	0.003	0.060	0.055	0.005
S1	1.000000	0.059	0.061	0.003	0.060	0.055	0.005
K1	1.002738	0.060	0.061	0.001	0.060	0.055	0.005
J1	1.039030	0.062	0.064	0.002	0.063	0.057	0.006
OO1	1.075940	0.064	0.066	0.002	0.065	0.059	0.006
2N2	1.864547	0.111	0.114	0.003	0.112	0.103	0.009
N2	1.895982	0.113	0.116	0.003	0.114	0.104	0.010
M2	1.932274	0.115	0.118	0.003	0.116	0.106	0.010
L2	1.968565	0.117	0.120	0.003	0.118	0.108	0.010
S2	2.000000	0.119	0.122	0.003	0.120	0.110	0.010
K2	2.005476	0.119	0.123	0.004	0.121	0.110	0.011
M3	2.898410	0.172	0.177	0.005	0.174	0.159	0.015

Table 5: Comparison of Instrumental Phase Lags from Step Response Experiments ST249V01 and ST249V02 with the Phase Lag of the SRW Built in Analog Filter.

wave (1)	frequency (2) [cpd]	ST249V01 (3) [°]	ST249V02 (4) [°]	diff. (4)-(3) [°]	average (6) [°]	filter (7) [°]	diff. (6)-(7) [°]
Q1	0.893244	0.056	0.054	-0.002	0.055	0.049	0.006
O1	0.929536	0.058	0.056	-0.002	0.057	0.051	0.006
M1	0.966446	0.060	0.059	-0.001	0.060	0.053	0.007
P1	0.997262	0.062	0.061	-0.001	0.062	0.055	0.007
S1	1.000000	0.062	0.061	-0.001	0.062	0.055	0.007
K1	1.002738	0.062	0.061	-0.001	0.062	0.055	0.007
J1	1.039030	0.065	0.063	-0.002	0.064	0.057	0.007
OO1	1.075940	0.067	0.065	-0.002	0.066	0.059	0.007
2N2	1.864547	0.116	0.113	-0.003	0.114	0.103	0.011
N2	1.895982	0.118	0.115	-0.003	0.116	0.104	0.012
M2	1.932274	0.120	0.117	-0.003	0.118	0.106	0.012
L2	1.968565	0.123	0.119	-0.004	0.121	0.108	0.013
S2	2.000000	0.125	0.121	-0.004	0.123	0.110	0.013
K2	2.005476	0.125	0.122	-0.003	0.124	0.110	0.014
M3	2.898410	0.180	0.176	-0.004	0.178	0.159	0.019

Table 6: Comparison of Instrumental Phase Lags from Step Response Experiments ST156V03, ST156V04, ST156V05 and ST156V06.

wave (1)	frequency (2) [cpd]	ST156V03 (3) [°]	ST156V04 (4) [°]	diff. (4)-(3) [°]	ST156V05 (6) [°]	ST156V06 (7) [°]	diff. (7)-(6) [°]
Q1	0.893244	0.534	0.520	-0.014	0.521	0.524	0.003
O1	0.929536	0.555	0.541	-0.014	0.542	0.546	0.004
M1	0.966446	0.577	0.562	-0.015	0.564	0.567	0.003
P1	0.997262	0.596	0.580	-0.016	0.582	0.586	0.004
S1	1.000000	0.597	0.582	-0.015	0.583	0.587	0.004
K1	1.002738	0.599	0.584	-0.015	0.585	0.589	0.004
J1	1.039030	0.621	0.605	-0.016	0.606	0.610	0.004
OO1	1.075940	0.643	0.626	-0.017	0.627	0.632	0.005
2N2	1.864547	1.114	1.085	-0.029	1.087	1.095	0.008
N2	1.895982	1.133	1.103	-0.030	1.106	1.113	0.007
M2	1.932274	1.154	1.125	-0.029	1.127	1.135	0.008
L2	1.968565	1.176	1.146	-0.030	1.148	1.156	0.008
S2	2.000000	1.195	1.164	-0.031	1.166	1.174	0.008
K2	2.005476	1.198	1.167	-0.031	1.170	1.177	0.007
M3	2.898410	1.731	1.687	-0.047	1.690	1.702	0.012

Table 7: Comparison of Instrumental Phase Lags from Step Response Experiments ST249V03, ST249V04, ST249V05 and ST249V06.

wave (1)	frequency (2) [cpd]	ST249V03 (3) [°]	ST249V04 (4) [°]	diff. (4)-(3) [°]	ST249V05 (6) [°]	ST249V06 (7) [°]	diff. (7)-(6) [°]
Q1	0.893244	0.523	0.516	-0.007	0.495	0.503	0.008
O1	0.929536	0.545	0.537	-0.008	0.515	0.524	0.009
M1	0.966446	0.566	0.558	-0.008	0.535	0.545	0.010
P1	0.997262	0.584	0.576	-0.008	0.553	0.562	0.009
S1	1.000000	0.586	0.577	-0.009	0.554	0.564	0.010
K1	1.002738	0.588	0.579	-0.009	0.556	0.565	0.009
J1	1.039030	0.609	0.600	-0.009	0.576	0.586	0.010
OO1	1.075940	0.631	0.621	-0.010	0.596	0.606	0.010
2N2	1.864547	1.093	1.077	-0.016	1.033	1.051	0.018
N2	1.895982	1.111	1.095	-0.016	1.051	1.069	0.018
M2	1.932274	1.132	1.116	-0.016	1.071	1.089	0.018
L2	1.968565	1.154	1.137	-0.017	1.091	1.110	0.019
S2	2.000000	1.172	1.155	-0.017	1.108	1.127	0.019
K2	2.005476	1.175	1.158	-0.017	1.111	1.130	0.019
M3	2.898410	1.699	1.674	-0.025	1.606	1.634	0.028

Table 8: Comparison of Instrumental Phase Lags from Step Response Experiments SFU1 ... SFU7 for Superconducting Gravity Meter TT60.

wave	frequency [cpd]	SFU1 [°]	SFU2 [°]	SFU3 [°]	SFU4 [°]	SFU5 [°]	SFU6 [°]	SFU7 [°]	average [°]	stdv.* [°]
Q1	0.893244	0.147	0.144	0.144	0.144	0.142	0.143	0.144	0.144	0.002
O1	0.929536	0.153	0.150	0.150	0.150	0.148	0.149	0.149	0.150	0.002
M1	0.966446	0.159	0.156	0.156	0.156	0.154	0.155	0.155	0.156	0.002
P1	0.997262	0.164	0.161	0.161	0.161	0.159	0.160	0.160	0.161	0.002
S1	1.000000	0.164	0.162	0.162	0.162	0.159	0.160	0.161	0.161	0.002
K1	1.002738	0.165	0.162	0.162	0.162	0.160	0.161	0.161	0.162	0.002
J1	1.039030	0.171	0.168	0.168	0.168	0.165	0.167	0.167	0.168	0.002
OO1	1.075940	0.177	0.174	0.174	0.174	0.171	0.173	0.173	0.174	0.002
2N2	1.864547	0.306	0.302	0.301	0.301	0.297	0.299	0.300	0.301	0.003
N2	1.895982	0.311	0.307	0.307	0.306	0.302	0.304	0.305	0.306	0.003
M2	1.932274	0.317	0.313	0.312	0.312	0.307	0.310	0.311	0.312	0.003
L2	1.968565	0.323	0.318	0.318	0.318	0.313	0.316	0.316	0.317	0.003
S2	2.000000	0.329	0.323	0.323	0.323	0.318	0.321	0.321	0.323	0.003
K2	2.005476	0.329	0.324	0.324	0.324	0.319	0.322	0.322	0.323	0.003
M3	2.898410	0.476	0.469	0.469	0.468	0.461	0.465	0.466	0.468	0.005

* = standard deviation for a single experiment

5 Conclusions

It has been shown, that the step response method can be used for the determination of the instrumental phase lag of earth tide gravity meters to an accuracy of about 1% of the magnitude of the phase lag. This corresponds for semidiurnal tidal waves to about 0.003^0 for systems with a moderate time lag of about 30 s, and to about 0.02^0 for systems with a large time lag of about 150 s. For precise earth tide recording, analog filters with a time lag not exceeding about 30 s should be used. Additional short periodic noise suppression should be made by sampling at a high rate of a few seconds and numerical filtering using symmetric numerical filters, which do not generate any time lag.

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ANALYSIS OF THIRD DEGREE WAVES WITH DIURNAL AND SEMIDIURNAL FREQUENCIES

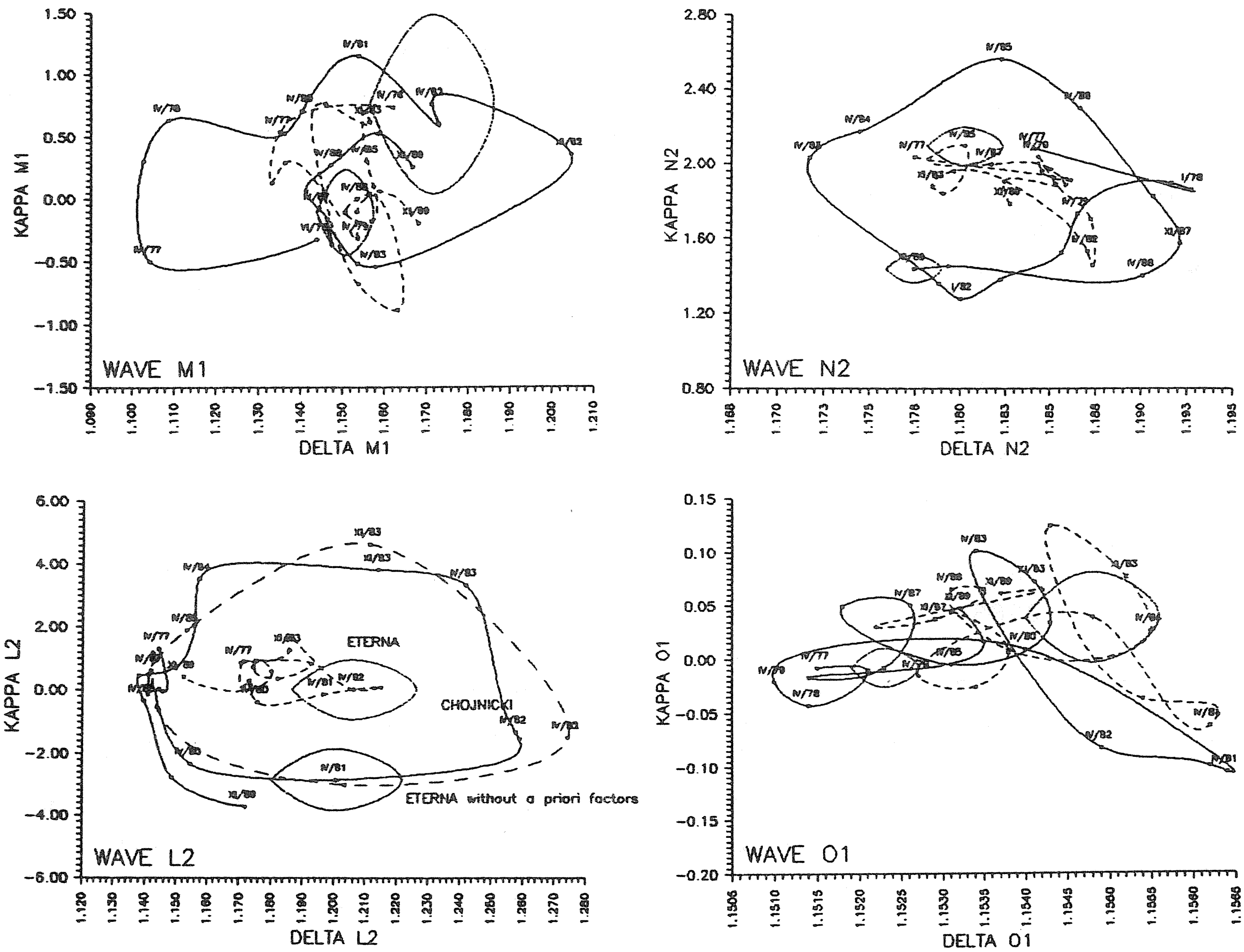
by Hans - Jürgen Dittfeld

Third degree constituents of the diurnal and semidiurnal tidal spectrum are generally included in the standard wave groups during tidal analyses not very much influencing the results because of their small amplitudes. But in several groups the amplitudes of the third degree members are almost in the same order as those of the name-giving waves. In such cases the analysis results during a long measuring period cannot be stable in time because of interferences inside the groups if the different amplitudes are disregarded. . But this is possible nowadays in the analysis program ETERNA / 6 / by the introduction of so-called a priori delta factors for each of the single tidal waves.

In a former paper there are reported the temporal variations of tidal results found from the long term tidal registration at Potsdam by gliding CHOJNICKI analysis of sections each with a duration of 480 days / 4 /. These analyses have been repeated with the ETERNA program but using the TAMURA 1987 potential of 1200 tidal waves, the a priori delta factors and the air pressure regression.

Figures 1 ... 3 show the variations of the resulting parameters of the wave groups M1, N2 and L2 inside the delta-kappa-polar-coordinate system (ETERNA - broken line, numbers beside points corresponds to central month of the analysis, error ellipses are marked). The temporal variations of the ETERNA results are clearly smaller than those of the former CHOJNICKI results. The only reason therefore is the use of the a priori delta factors corresponding to the Earth model of WAHR, DEHANT and ZSCHAU / 2,3 /: As shown in the picture of the L2 wave variations ETERNA gives nearly the same results as CHOJNICKIs method if the a priori delta factors are not introduced.

As already discussed by SCHWAHN and others / 5 / the comparable big variations of the M1, N2 and L2 parameters are caused by the mentioned interferences of third degree waves with the main waves inside these groups. The frequencies of these waves are very near together in the spectrum. Therefore the period of the interference is very long and amounts to 8.85 years corresponding to the period of the perigeum of the moon.



Figures 1 4

The differences in frequency between the main waves and the third degree waves in these groups are

$M1^* - M1 = -\ 0.00464\ ^{o}/h$

$N2^* - N2 = -\ 0.00464\ ^{o}/h$

$L2^* - L2 = +\ 0.00464\ ^{o}/h.$

With the 17 years' tidal registration at Potsdam of 135 228 hourly readings evaluated until now it was possible to separate wave groups with a frequency difference of more than only 0.0027 °/h. So are analysed the third degree waves directly during a processing with a resolution of 73 wave groups with CHOJNICKIs method as well as with the maximum resolution of 30 wave groups by the ETERNA program. The results of table 1 nearly confirm with their comparable small errors the delta value of 1.07 adopted in / 5 / from LOVEs theory for the third degree waves, to explain the temporal variations of the former results.

Wave	Chojnicki A15K		ETERNA		W.-D.-model
	DELTA	A/μGal	DELTA	A/μGal	DELTA
M1*	1.0888	0.89	1.0848	0.837	1.0728
	.0085		.0104		
N2*	1.0927	0.58	1.0912	0.590	1.0728
	.0056		.0074		
L2*	1.0825	0.54	1.0834	0.541	1.0728
	.0060		.0080		
M3	1.0712	0.32	1.0722	0.361	1.0690
	.0090		.0096		
K3	1.0817	0.05	1.0769	0.047	1.0690
	.0388		.0722		

Table 1 GS15 No. 222 Potsdam, 1974 - 1990
Amplitudes of 3rd degree waves in high resolution analyses

Full listings of the results of the whole series are given in tables 3 and 4. The Chojnicki results of table 1 are corrected towards the ellipsoide, and because of man made disturbances in the first years of observation the M3 results as the only exception are taken from the period 1982 - 1989.

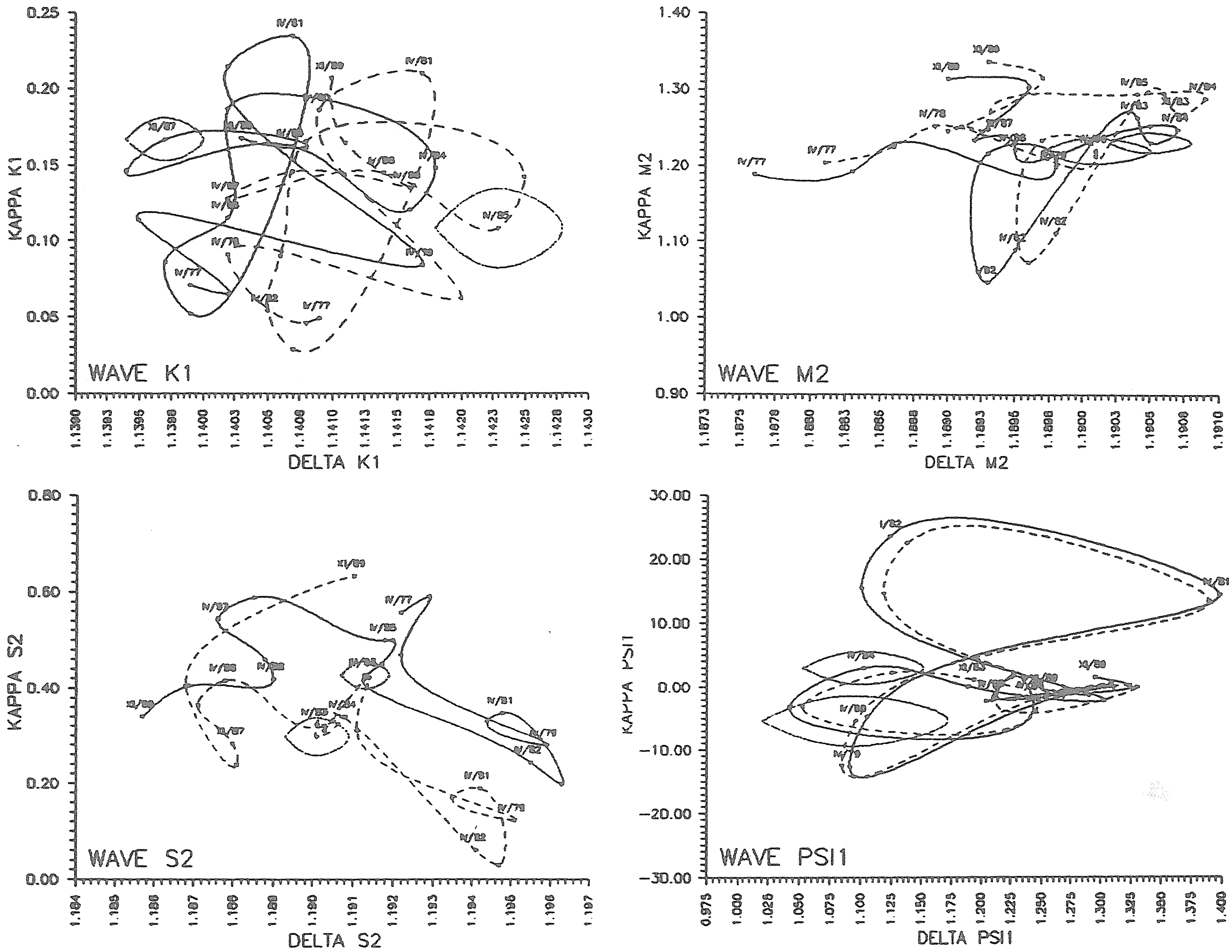
It is remarkable, that all the calculated amplitudes of third degree wave groups are higher than the model values by about one percent.

After separation of the third degree waves the amplitudes of the "normal" M1, N2 and L2 constituents very well agree within the error limits for both the analysis methods. While M1 came near to the model value, N2 is higher by about 0.4% if the SCHWIDERSKI correction is applied. Also the other results corrected for the indirect effect of the oceans (table 2) are bigger than the model values by about 0.4%, and after separation of the third degree waves the scattering around this value is comparably small. So the deviation seems to be real and may be caused by a deviation of the calibration level. This is supported also by corresponding differences of about 0.5% for O1 and 0.2% for M2 against modern tidal measurements in western Europe as reported by BAKER, WENZEL and others / 1,6 /. In order to decide whether the calibration or other reasons are responsible for these discrepancies the GS 222 gravimeter will be proved in the near future like in / 6 / by intercomparison with calibrated LaCoste-Romberg instruments.

Wave	ETERNA		Indirect effect corrected		W.-D. model	DELTA / DELTA model
	DELTA	KAPPA	DELTA	KAPPA	DELTA	
Q1	1.1504	-0.302	1.1560	- 0.117	1.1529	1.0027
O1	1.1540	0.053	1.1583	- 0.053	1.1527	1.0049
M1	1.1532	0.021	-	-	1.1521	-
P1	1.1541	0.233	1.1526	0.091	1.1472	1.0047
K1	1.1413	0.150	1.1391	0.032	1.1317	1.0065
N2	1.1815	1.915	1.1613	0.085	1.1571	1.0036
M2	1.1897	1.261	1.1610	- 0.143	1.1571	1.0034
L2	1.1841	0.452	-	-	1.1571	-
S2	1.1904	0.298	1.1636	- 0.106	1.1571	1.0056
K2	1.1880	0.128	1.1622	- 0.158	1.1571	1.0044

Tab. 5 Results and values corrected for the indirect effect of the oceans

Beside the waves M1, N2 and L2 also the ETERNA results for the main waves are shifted a small amount but systematically against the CHOJNICKI results (fig. 4...6) even if the ellipsoide correction is regarded. The differences are small in average, for instance +0.10% / +0.025° for O1, +0.07% / -0.021° for K1 and +0.01% / +0.024° for M2, respectively.



Figures 5 ... 8

In case of S2 a shift of -0.1% in amplitude but significant -0.17° in phase (fig. 7) was found. This is only caused by the air pressure regression and not by the a priori delta factors because it also exists in ETERNA analyses without a priori delta factors. Furthermore the temporal S2 variation is not diminished by ETERNA, indicating, that the variation is not caused by influences of the tidal model used during the analyses. That is why S2 contains only a very small amount of third degree constituents.

An example of nearly identical temporal variations of both the series of results was found in case of the very small wave PSI1 (fig. 8).

It may be concluded that third degree waves of diurnal and semi-diurnal frequencies are directly evaluable from gravimetric tidal measurements if a registration period of more than ten years is available. Apart from an almost constant difference possibly caused by calibration problems the results are in accordance with the WAHR-DEHANT-ZSCHAU model and they are fully explaining the former observed temporal variations of analysis results.

We thank Professor H.-G. WENZEL / University of Karlsruhe / for making available the ETERNA program and for helpful dicussions during its installation.

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Mitteilung des Zentralinstituts für Physik der Erde Nr. 1941

Table 3 CHOJNICKI result (without ellipsoide correction,
Potsdam 1974-1990 instrumental phase lag not regarded)

TOTAL NUMBER OF DAYS: 5920 - 135338 READINGS

WAVE GROUP ARGUMENT	N	SYMBOL	ESTIM.AMPL. VALUE	ESTIM.AMPL. R.M.S.	AMPLITUDE FACTOR VALUE	AMPLITUDE FACTOR R.M.S.	PHASE DIFFERENCE VALUE	PHASE DIFFERENCE R.M.S.	RESIDUALS' AMPL.	RESIDUALS' PHASE
105.-109.	3	130	0.05	0.01	0.95156	0.18037	0.935	10.861	0.01	175.7
115.-115.	3	134	0.11	0.01	1.16335	0.08703	5.450	4.286	0.01	91.0
116.-11X.	8	SMQ1	0.27	0.01	1.14842	0.03250	-2.823	1.622	0.01	-103.0
124.-125.	7	2Q1	0.96	0.01	1.16398	0.00927	0.899	0.456	0.02	78.4
126.-127.	8	SIG1	1.06	0.01	1.14616	0.00762	-0.244	0.381	0.01	-160.7
128.-129.	6	159	0.05	0.00	0.99029	0.10308	7.078	5.964	0.01	145.5
133.-134.	4	167	0.04	0.00	1.09883	0.13216	3.931	6.892	0.00	130.3
135.-135.	11	Q1	6.75	0.01	1.14888	0.00118	-0.446	0.059	0.08	-141.1
136.-136.	5	183	0.07	0.01	1.00909	0.11285	-6.356	6.407	0.01	-144.6
137.-137.	6	RO1	1.29	0.01	1.14964	0.00617	-0.897	0.308	0.02	-120.4
138.-139.	4	191	0.04	0.01	0.99010	0.12995	-13.906	7.520	0.01	-129.9
143.-144.	6	198	0.08	0.00	1.22526	0.04948	-1.352	2.314	0.00	-24.0
145.-145.	10	O1	34.16	0.01	1.15213	0.00022	-0.123	0.011	0.25	-162.7
146.-146.	2	211	0.08	0.01	0.96036	0.07675	-1.918	4.579	0.02	-170.9
147.-149.	8	TAU1	0.42	0.01	1.16523	0.01637	0.783	0.805	0.01	72.5
152.-154.	5	222	0.23	0.01	1.18738	0.02930	-0.870	1.414	0.01	-33.6
155.-155.	3	227	0.97	0.01	1.14965	0.00778	0.122	0.388	0.01	166.7
155.-155.	3	M1*	0.89	0.01	1.08787	0.00850	0.309	0.448	0.06	175.4
155.-155.	4	M1	2.71	0.01	1.15082	0.00279	-0.152	0.139	0.02	-161.6
156.-158.	7	CHI1	0.47	0.01	1.14753	0.01440	0.135	0.719	0.01	167.9
161.-161.	1	242	0.04	0.01	1.29565	0.19802	-24.449	8.757	0.02	-87.9
162.-162.	2	PI1	0.96	0.01	1.16352	0.00809	-0.048	0.399	0.00	-15.9
163.-163.	7	P1	16.18	0.01	1.15240	0.00047	0.134	0.024	0.10	158.6
164.-164.	3	S1	0.12	0.01	0.51856	0.02864	81.686	3.164	0.28	154.7
165.-165.	11	K1	47.73	0.01	1.13969	0.00016	0.002	0.008	0.87	179.9
166.-166.	2	PSI1	0.40	0.01	1.19465	0.01976	0.205	0.948	0.01	7.1
167.-167.	6	PHI1	0.70	0.01	1.18217	0.01116	2.328	0.541	0.03	66.3
168.-168.	1	274	0.03	0.01	0.99089	0.18972	-12.875	10.969	0.01	-131.3
172.-173.	6	THE1	0.50	0.01	1.17384	0.01456	0.402	0.711	0.01	30.9
174.-177.	16	J1	3.07	0.01	1.16112	0.00282	-0.222	0.139	0.01	-76.6
181.-184.	8	SO1	0.44	0.01	1.15662	0.01722	2.279	0.853	0.02	95.4
185.-186.	10	OO1	1.14	0.00	1.15424	0.00435	0.197	0.216	0.01	145.7
191.-193.	8	317	0.04	0.00	1.24087	0.08004	0.812	3.696	0.00	12.3
195.-195.	6	NY1	0.27	0.01	1.16095	0.02407	-0.722	1.188	0.00	-87.0
1X3.-1X3.	2	329	0.04	0.01	1.04681	0.15743	3.898	8.617	0.01	148.4
1X5.-1E3.	3	331	0.03	0.01	1.09919	0.18639	-2.985	9.768	0.00	-140.2
207.-21X.	8	338	0.05	0.00	1.04564	0.07891	3.379	4.324	0.01	152.1
225.-226.	5	3N2	0.12	0.00	1.14870	0.03902	2.875	1.946	0.01	102.6
227.-228.	5	EPS2	0.25	0.00	1.11775	0.01536	2.740	0.787	0.02	129.2
229.-22X.	3	353	0.04	0.00	1.07873	0.07826	3.387	4.156	0.00	142.6
233.-236.	10	2N2	1.00	0.00	1.16157	0.00434	1.462	0.214	0.03	87.9
237.-237.	4	MY2	1.04	0.00	1.16365	0.00360	2.215	0.177	0.04	86.6
238.-23X.	6	371	0.05	0.00	1.14507	0.04913	1.255	2.458	0.00	121.4
243.-245.	5	378	0.02	0.00	1.20700	0.05803	2.024	2.755	0.00	42.7
245.-245.	3	N2*	0.58	0.00	1.08813	0.00559	-0.239	0.294	0.04	-176.4
245.-245.	5	N2	6.39	0.00	1.17678	0.00057	1.574	0.028	0.20	63.3
246.-246.	4	391	0.08	0.00	1.16928	0.05287	4.047	2.590	0.01	85.7
247.-247.	5	NY2	1.23	0.00	1.18374	0.00296	1.261	0.143	0.04	48.1
248.-248.	2	398	0.05	0.00	1.07894	0.06369	3.675	3.382	0.01	140.3
252.-253.	5	GAM2	0.13	0.00	1.24421	0.03537	3.825	1.629	0.01	45.6
254.-254.	3	ALF2	0.13	0.00	1.29402	0.03104	-9.973	1.374	0.03	-63.0
255.-255.	10	M2	33.61	0.00	1.18446	0.00011	0.925	0.005	0.88	38.3
256.-256.	2	BET2	0.11	0.00	1.24232	0.03486	15.459	1.608	0.03	83.6
257.-258.	6	DLT2	0.04	0.00	1.17762	0.06653	5.158	3.237	0.00	83.1
262.-264.	5	LMB2	0.23	0.00	1.16643	0.01437	-0.282	0.706	0.00	-42.3
265.-265.	2	L2	0.94	0.00	1.17660	0.00378	0.259	0.184	0.01	17.9
265.-265.	3	L2*	0.54	0.00	1.07795	0.00596	-0.119	0.317	0.04	-178.4
265.-267	7	436	0.24	0.00	1.16847	0.01359	0.865	0.666	0.00	65.0
271.-271.	1	2T2	0.04	0.00	1.35067	0.09587	2.412	4.067	0.01	16.7
272.-272.	1	T2	0.90	0.00	1.17779	0.00391	-0.325	0.190	0.01	-20.7
273.-273.	4	S2	15.52	0.00	1.18656	0.00023	0.102	0.011	0.35	4.6
274.-274.	3	R2	0.16	0.00	1.15644	0.02217	4.024	1.098	0.01	94.6
275.-277.	9	K2	3.97	0.00	1.18087	0.00081	-0.116	0.039	0.07	-6.6
282.-283.	7	KSI2	0.03	0.00	1.11022	0.07144	-0.388	3.687	0.00	-171.4
285.-285.	8	ETA2	0.28	0.00	1.19086	0.01420	-0.292	0.683	0.01	-11.2
292.-293.	4	476	0.04	0.00	1.28350	0.08684	4.453	3.877	0.00	39.8
295.-2X5.	10	2K2	0.02	0.00	1.16028	0.04092	0.334	2.020	0.00	88.6
327.-347.	6	N3	0.09	0.00	1.04962	0.02098	-1.473	1.145	0.00	-123,8
353.-365.	7	M3	0.38	0.00	1.03502	0.00578	-0.604	0.320	0.01	-161.4
375.-375.	4	K3	0.05	0.00	1.07715	0.03884	-0.780	2.066	0.00	-56.5
382.-382.	1	S3	0.02	0.00	0.18644	0.01845	-161.865	5.671	0.12	-177.3
455.-455.	1	M4	0.01	0.00	0.10186	0.01534	75.552	8.627	0.01	75.5
491.-491.	1	S4	0.01	0.00	0.06271	0.01540	58.847	14.068	0.01	58.8

R.M.S.ERROR : 0.5848 MICROGAL

R.M.S.ERROR FOR BANDS: D 1.7277 SD 0.7806 TD 0.5106 QD 0.4004

Table 4 ETERNA result

GRAVIMETRIC EARTH TIDE STATION NR. 764
GRAVIMETRIC OBSERVATORY POTSDAM, CENTRAL INSTITUTE FOR PHYSICS
OF THE EARTH, - GEODETIC INSTITUTE POTSDAM -
52.3806N 13.0682E H 81M P 1M VERTICALCOMPONENT
GRAVIMETER ASKANIA GS 15 NO. 222 ELECTROMAGNETIC CALIBRATION
1974 03. 21 - 1990 06. 06
INSTALLATION: H.-J. DITTFELD, POTSDAM
MAINTENANCE: H.-J. DITTFELD, W. ALTMANN

INSTRUMENTAL LAG CORRECTED FOR 0.421 DEG O1 AND 0.876 DEG M2
INITIAL EPOCH FOR TIDAL FORCE : 1982.10.31. 0
NUMBER OF RECORDED DAYS IN TOTAL : 5662.0
TAMURA 1987 TIDAL POTENTIAL USED.
WAHR-DEHANT-ZSCHAU INELASTIC EARTH MODEL USED FOR A PRIORI AMPLITUDES.
UNITY WINDOW USED FOR LEAST SQUARES ADJUSTMENT.
NUMERICAL FILTER IS PERTZEV 1959 WITH 51 COEFFICIENTS.

ESTIMATION OF NOISE BY FOURIER-SPECTRUM OF RESIDUALS
0.1 CPD BAND 9999.9999 NM/S**2 1.0 CPD BAND .0803 NM/S**2
2.0 CPD BAND .0398 NM/S**2 3.0 CPD BAND .0325 NM/S**2
4.0 CPD BAND .0221 NM/S**2

ADJUSTED TIDAL PARAMETERS :

NO.	FROM	TO	WAVE	OBS.AMPL. NM/S**2	SIGNAL/ NOISE	AMPL.FAC.	STDV.	PHASE LAG DEGREE	STDV. DEGREE
1	282	373	SIG1	10.572	131.6	1.15054	.00874	.4694	.4353
2	374	424	Q1	66.192	824.1	1.15039	.00140	-.3021	.0695
3	425	482	O1	346.801	4317.9	1.15399	.00027	.0531	.0133
4	483	499	499	9.893	123.2	1.16421	.00945	.4538	.4652
5	500	505	M1*	8.367	104.2	1.08476	.01041	.1901	.5500
6	506	512	M1	27.256	339.4	1.15321	.00340	.0207	.1688
7	513	530	CHI1	5.206	64.8	1.15171	.01777	.4321	.8839
8	531	547	P1	161.376	2009.3	1.15407	.00057	.2327	.0285
9	548	551	S1	1.941	24.2	.58669	.02428	77.4328	2.3711
10	552	569	K1	482.354	6005.7	1.14127	.00019	.1504	.0095
11	570	573	PSI1	3.951	49.2	1.19433	.02428	-.0387	1.1648
12	574	586	PHI1	7.091	88.3	1.17810	.01334	2.3982	.6489
13	587	601	THE1	5.304	66.0	1.17369	.01777	.4660	.8676
14	602	626	J1	27.494	342.3	1.16333	.00340	-.1407	.1674
15	627	731	OO1	14.982	186.5	1.15832	.00621	.4256	.3072
16	732	786	EPS2	2.347	59.0	1.13460	.01922	2.7845	.9706
17	787	818	2N2	10.007	251.7	1.16864	.00464	2.4260	.2277
18	819	842	839	.678	17.1	1.17293	.06879	-.6869	3.3601
19	843	846	N2*	5.904	148.5	1.09123	.00735	-.0204	.3858
20	847	855	N2	63.351	1593.3	1.18153	.00074	1.9154	.0360
21	856	872	NY2	12.102	304.4	1.18836	.00390	1.4618	.1882
22	873	936	M2	333.174	8379.4	1.18971	.00014	1.2614	.0068
23	937	949	LMB2	2.391	60.1	1.15793	.01925	-.3706	.9527
24	950	953	L2	9.373	235.7	1.18411	.00502	.4523	.2431
25	954	957	L2*	5.407	136.0	1.08335	.00797	.2904	.4213
26	958	975	959	2.367	59.5	1.19517	.02008	1.2674	.9626
27	976	996	S2	155.094	3900.7	1.19036	.00031	.2978	.0147
28	997	1108	K2	42.084	1058.4	1.18797	.00112	.1251	.0541
29	1109	1190	M3	3.498	107.8	1.03953	.00965	-.4038	.5316
30	1191	1200	M4	.071	3.2	1.90343	.59060	-106.0206	17.7778

STANDARD DEVIATION 7.076 NM/S**2 DEGREE OF FREEDOM135027

ADJUSTED METEOROLOGICAL OR HYDROLOGICAL PARAMETERS :

NO.	REGR.COEFF.	STDV.	PARAMETER
1	-.01215	.00022	AIRPRES.PASCAL

A PARTICULAR STUDY OF THE RELATION BETWEEN EARTH TIDE DATA AND OTHER TIME SERIES

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1. Introduction.

The problem to be considered here is the following:

We have a given tidal observation or a tidal record G. We know or we suppose that G can be influenced or perturbed by another phenomenon P. Most interesting is the case when P is the air-pressure or temperature variation. However, P can be any time varying process, for example a given water level.

P is observed in parallel with G and a corresponding record or time series is obtained. The problem is to establish what the effect ΔG of P on the observed G is.

The problem is a very sophisticated one, without an unique solution. We have to decide and define: (i) what is ΔG, (ii) which parts ΔP of P and ΔG of G are related, and (iii) what is the analytical expression of the relation. In addition the solutions of these three points cannot be conformed to a strict physical theoretical model. We have at least the limitation that usually P, for example the air-pressure, is acting on large Earth surfaces, while we are restricted to use data about P from a single point.

Thus the solution is always a subjective and empirical one, with a rather low precision. We make this statement for the following reasons: (i) in order to explain our efforts to find our solution of the problem, (ii) to avoid a very severe criticism of our model and the imperfection of our results, and (iii) to worn the users of our and other results against a too great optimism.

We think that point (iii) just mentioned above is a particularly important one. In the tidal "milieu" one can often hear expressions like "we have introduced an air-pressure correction with a coefficient 0.3...". Behind such a statement is an unjustified belief that the air-pressure is no more existing in the data. It ignores that an error in the coefficient of, say, 0.05 means the introduction of an error equal to 0.05 times the air-pressure.

2. The model used.

A given tidal component of G with an angular frequency (angular velocity) ω will be represented in the usual way as

(1) $$g(T+t) = H \cos [\Phi(T) + \omega t] = u(T) \cos \omega t + v(T) \sin \omega t$$

$$u(T) = H \cos \Phi(T) \quad , \quad v(T) = -H \sin \Phi(T)$$

where H is the observed amplitude and $\Phi = \Phi(T)$ is the observed phase at time T at which t=0.

We shall suppose that P incorporates a component p(T+t) with the same frequency ω. It can be represented in a similar way as (1), namely

$$(2) \qquad p(T+t) = h \cos [\phi(T) + \omega t] = x(T) \cos \omega t + y(T) \sin \omega t$$

$$x(T) = h \cos \phi(T) \quad , \quad y(T) = -h \sin \phi(T)$$

Our basic idea (Venedikov, 1989; Simon, Stanchev, de Toro, Venedikov & Vieira , 1989) is that the term (2) generates in the observed G a perturbation which can be represented as

$$(3) \qquad \Delta g(T+t) = b.p(T+t+\beta) = b.h \cos [\phi(T) + \omega t + \beta]$$

$$= b.h \cos [\phi(T) + \beta] \cos \omega t - b.h \sin [\phi(T) + \beta] \sin \omega t$$

where b is an unknown coefficient of proportionality and β is an unknown phase shift.

The term (3) is to be added to (1). Then the effect of (2) on (1) can be expressed as a modification of u(T) by $\Delta u(T)$ and of v(T) by $\Delta v(T)$ where

$$(4) \qquad \begin{aligned} \Delta u(T) &= b\ h \cos [\phi(T) + \beta] \\ \Delta v(T) &= -b\ h \sin [\phi(T) + \beta] \end{aligned}$$

or

$$(5) \qquad \begin{aligned} \Delta u(T) &= b_1.x(T) - b_2.y(T) \\ \Delta v(T) &= b_1.x(T) + b_2.y(T) \end{aligned}$$

where

$$(6) \qquad b_1 = b \cos \beta \quad \text{and} \quad b_2 = b \sin \beta \ .$$

If we have x(T), y(T), $\Delta u(T)$ and $\Delta v(T)$ for a sequence of values of the time T we can consider (5) as a system of regression equations with b_1 and b_2 as unknown coefficients. The solution of this system after the method of the least squares will provide us estimates of the unknowns b_1 and b_2 , respectively b and β. These quantities can be used as a characteristic of the influence of P on G. The remaining problem now is how to define the quantities x(T) and y(T) from the perturbating process P as well as $\Delta u(T)$ and $\Delta v(T)$ from the observed tide G.

All terms are related with a given frequency ω. Thus we have to create equations separately for different ω. Practically we are not able to go very far in the separation of the frequencies. We have at least the limitation that in P, as far as it is related with the meteorological phenomena, we cannot expect important waves and oscillations but the basic D, SD, TD and QD periods, i.e. we may consider only a set of frequencies like ω = 15, 30, 45 and 60 $^\circ$/hour.

3. Filtered numbers.

In the first stage of the analysis of tidal data (Venedikov, 1966, 1977) we apply a couple of even and odd filters for each one of the D, SD, TD and QD tides. This means that we have a couple of D-filters which amplify the D tides with ω close to $15^\circ/h$ and eliminate all other frequencies, then we have SD-filters which amplify all SD tides and so on.

The filters are applied on intervals of length N hours (very often N=48) without overlapping. Let T is the central epoch of a given filtered interval. We shall denote by U=U(T) and V=V(T) (M_i and N_i in some earlier versions) the couple of filtered numbers obtained from this interval and corresponding to one of the main tidal species, D, SD, TD or QD.

About U and V we have theoretical (model) expressions like

$$U(T) = \sum_i c_i H_i \cos \Phi(T) \quad , \quad V(T) = -\sum_i s_i H_i \sin \Phi(T) \tag{7}$$

Here c_i and s_i are the amplifying factors (the response) of the corresponding filters to the i-th tidal wave. For the tides which are amplified c_i and s_i are close to 1, while they are close to zero for the remaining tides. Thus for the D-filters c_i and s_i are close to 1 for the D tides or $\omega = 15^\circ/h$ and they are close to zero for SD, TD and QD tides.

In the expression (7) H_i and $\Phi_i(T)$ are the observed amplitudes and phases. Here we have in mind some well determined values of H_i and Φ_i. That is why there is added an index $_o$ to the filtered numbers. Thus we distinguish between these theoretical filtered numbers, U_o and V_o , and the observed filtered numbers U and V. The later are charged by some errors or a noise and perturbations, including the effect of the perturbating phenomenon P.

On the basis of the expressions (7) and these properties of the amplifying factors we can use the filtered numbers U and V as u(T) and v(T) in the previous paragraph. Namely the differences

$$\begin{aligned} \Delta U(T) &= U(T) - \sum_i c_i H_i \cos \phi_i(T) = U(T) - U_o(T) \\ \Delta V(T) &= V(T) - [-\sum_i s_i H_i \sin \phi_i(T)] = V(T) - V_o(T) \end{aligned} \tag{8}$$

can be included in the regression equations (5).

Here U_o and V_o are model or theoretical or smoothed values corresponding to the observed filtered numbers. From the analysis we obtain the tidal parameters δ and χ and with them we can determine the observed amplitudes H_i and the observed phases Φ_i. Thus we can get the values of U_o and V_o for each filtered interval, i.e. for each T. Then we can compute ΔU and ΔV which can be called residuals of the filtered numbers.

Evidently, it is natural to use as $x(T)$ and $y(T)$ in (5) the filtered numbers obtained by the same filters and the same time intervals of the process P. However there is another possibility which may seem to be a reasonable one.

We can process the data P as a tidal record and determine parameters analogical to δ and κ and the corresponding observed amplitudes and phases. Then, after expressions similar to (8), we can compute residuals $\Delta x(T)$ and $\Delta y(T)$ of the filtered numbers $x(T)$ and $y(T)$. These residuals, as they are analogous with ΔU and ΔV, can be used in the regression equations (5).

In our experimental computations we have tried both variants, i.e. $x(T)$ and $y(T)$, as well as $\Delta x(T)$ and $\Delta y(T)$. For the data which are here discussed $x(T)$ and $y(T)$ have provided a considerably higher precision. That is why the results given in the present paper are based on the filtered numbers $x(T)$ and $y(T)$.

After we get the residuals $\Delta U(T)$ and $\Delta V(T)$ and the corresponding $x(T)$ and $y(T)$, for a given sequence of T, the equations (5) can be processed, as we have already mentioned, as a system of regression equations. It is reasonable to include, in the right side of (5), two arbitrary unknown constants and to use (5) as

(9) $$\Delta U = a_1 + b_1 \kappa - b_2 y, \qquad \Delta V = a_2 + b_1 \kappa - b_2 y.$$

These constants a_1 and a_2 are eliminated by replacing (9) through

(10) $$\Delta U - \overline{\Delta U} = b_1(x-\bar{x}) + b_2 (y-\bar{y})$$
$$\Delta V - \overline{\Delta V} = b_1(y-\bar{y}) + b_2 (x-\bar{x})$$

where — means an arithmetic mean.

4. Two particular series of gravity observations.

Here we shall present some results from the application of the described model and technology on two particular series of observations.

In March 1986, in the framework of the Iberian tide-gravity network, a new station was installed in the city of Oviedo (North of Spain). The station was situated in the building of the Faculty of Geological Sciences in Oviedo. The equipment used was a LaCoste and Romberg gravimeter G/434 with a zero-method incorporated by M. Van Ruymbeke.

The results of the analysis of the data have shown important anomalies, in particular a too high level of the estimated noise in the diurnal band. A careful study of the possible origin of the perturbations (Vieira et al., 1988) has established the following.

The building has suffered from the neibourhood of geological Cretaceous-Tertiary discontinuity. It has caused some cracks in the facade. In order to keep the building safe it has been closed in a metal solid frame. The frame is more sensitive to the solar direct heating as an usual construction. Due to that it has been established that on sunny days there is a considerable deformation of the building, namely an inclination in the direction NS.

The sensibility of the gravimeter is sensitive to the inclination. In the direction of the longitudinal level the effect is 16.5 μgal/sec. of arc and in the direction of the transversal level it is 0.6 μgal/sec. of arc. Taking into account the orientation of the gravimeter within the building (azimuth 45° from the North) by studying the variation of the sensibility, it has been established that the inclinations of the building are of the order of 1.4.

The observations in this station continued 6 months, 22.03.1986 - 11.09.1986. After that the instrument was moved in another building, in the faculty of Physical Sciences, situated at only 500 m. from the first place. The observations continued at the new place also 6 months, 30.09.1986 - 23.03.1987.

The analysis results from the two series are presented in Table 1.a and Table 1.b respectively. Here and further the first series of data is indicated as Oviedo 1 and the second - as Oviedo 2. It is evident that there are cosiderable and significant differences especially in the D tides. The mean square errors in Oviedo 1 are much higher than in Oviedo 2. The meteorological waves S2, S3 and S4 in Oviedo 1 have higher amplitudes than in Oviedo 2.

The length of both series is a little bit under the critical length of 6 months, which is necessary for the separation of P1 from K1, as well as K2 from S2. That is why we have processed the analysis in two variants: with and withot such a separation. It has been established, through the method of the analysis of variances, that the results of these variants are significantly different. The variant with the separation has given somewhat lower mean square errors. The difference was more important for Oviedo 1.

All this is an indication that we have two series of gravity data, one of them submitted to a particularily important effect of the temperature, in any case much higher than the other one. This offers a good opportunity to test the method for studying the effect of a perturbating phenomenon P, in this case P being the temperature, on the gravity observations.

5. Some results.

As it was mentioned above, in order to compute the theoretical or model filtered numbers (7) for the gravity data we need to determine first the tidal parameters δ and κ. For the series Oviedo 1 we have used two different sets of δ and κ, respectively two different variants of values (7) and residuals (8). In Tables 2, 3 and 4 these variants are indicated as "model 1" and "model 2".

For the first one we have taken δ and κ derived by the analysis of the series Oviedo 1 itself. For the other one, it is "model 2", we have applied on Oviedo 1 δ and κ obtained from Oviedo 2. Thus in "model 2" we have used strongly perturbated gravity data with δ and κ which are less perturbated. In such a way in the residuals "model 2" we can expect a stronger manifestation of the effect of the temperature.

For Oviedo 2, naturally, we have used only the corresponding δ and κ, i.e. only "model 2".

Table 2 is a demonstration for the study of the stochastic distribution of the data used in the processing by the help of the χ^2 criterion of Pearson. The space $[-\infty,+\infty]$ of the variable which is studied is subdivided into unequal subintervals. The last ones are defined in such a way that the expected number of events when the variable happens to be in a given interval is a constant ≥ 10.

The residuals for SD only are presented, for Oviedo 1, models 1 and 2.

It can be seen that for "model 1" a hypothesis for a normal distribution cannot be rejected. On the contrary, for "model 2" there is a significant deviation from the normal distribution. In a similar way it was established that the filtered numbers x(T) and y(T) of the temperature data as well as the residuals ΔU and ΔV for Oviedo 2 have a normal distribution.

The general problem which we discuss here allows many different solutions. Here we propose only one of them, namely to use filtered numbers. Still in this case we have many options by applying different filters.

We have tested filters with lengths N = 36, 42 and 48. which eliminate a drift polynomial of power k=1 or k=2. The results for the D tides is presented in Table 3. It can be stated that there is an acceptable coherency between the resuts. The variations can be explained, more or less, through the mean square errors. An exception is the case N=36, k=2. An explanation is that within a time interval of 36 hours it is difficult to separate the tides between themselves and eliminate a second power. That is why the corresponding filters have a low weight, i.e. a low ratio signal/noise.

In Table 4 our final results are given. The filters selected are N=36, k=1. For these filters the mean square errors appeared to be relatively the lowest ones.

Generally we have indeed a much stronger effect in Oviedo 1 than in Oviedo 2. The precision in Oviedo 1 is lower than in Oviedo 2. Nevertheless, the coefficients b_1 and b_2 as a couple are significant (compared to the mean square error which is equal for both coefficients).

There is a drastic difference between "model 1" and "model 2" for D and less important difference for SD and TD. For QD the theoretical term (7) is equal to zero and the result does not depend on the model used.

For Oviedo 2 we have a higher precision but the coefficients for D are not significantly different from the zero, while for SD and QD they are scarcely over the critical limit of significance (we have in mind a confidential probability p = 0.95 or level of significance α = 0.05). A somewhat unexpected result are the relatively high coefficients for TD.

Generally we have an important variation for the main tidal species, D, SD, TD and QD. In our opinion this justifies, in principle, our way to consider separately the basic frequencies.

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The computer program SV which was applied is achieved in its present state during the stay of one of the authors, A.Venedikov, as an invited professor in the University of Kiel, under the direction of prof. J. Zschau. This stay was supported by a grant of Deutsche Forschungsgemeinschaft.

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Table 1.a. Analysis results from Oviedo 1

G 860322/860429 860504/860507 860508/860623 860626/860721
G 860724/860814 860816/860830 860831/860910

WAVE ARGUM.	GROUP N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPLIT. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.
105-139	65	Q1	7.060	.249	1.1887	.0419	-3.179	2.025
143-149	26	O1	35.357	.249	1.1397	.0080	-.397	.403
152-158	22	NO1	2.898	.258	1.1880	.1059	.390	5.108
161-163	10	P1	16.223	.292	1.1236	.0202	18.654	1.030
164-168	23	K1	48.831	.257	1.1192	.0059	4.444	.302
172-177	22	J1	2.680	.251	1.0986	.1027	7.163	5.347
181-1I3	37	OO1	1.549	.170	1.1587	.1273	3.287	6.292
207-23X	41	2N2	.924	.083	.9182	.0828	8.202	5.140
243-248	24	N2	7.770	.127	1.0218	.0167	11.907	.929
252-258	26	M2	45.286	.118	1.1402	.0030	10.549	.149
262-267	17	L2	1.362	.062	1.2129	.0550	6.101	2.589
271-273	6	S2	23.330	.112	1.2625	.0061	8.300	.275
274-2X5	41	K2	5.816	.087	1.1568	.0174	9.917	.857
327-375	17	M3	.614	.046	1.0821	.0809	-6.694	4.249
382-382	1	S3	.4850	.0449				
455-455	1	M4	.0685	.0232				
491-491	1	S4	.1746	.0208				

STANDARD DEVIATIONS D 2.73 SD 1.07 TD .44 QD .21

Table 1.b. Analysis results from Oviedo 2

G 860930/861111 861119/861219 861222/861230 870103/870106
G 870108/870212 870217/870218 870221/870227 870301/870305
G 870309/870323

WAVE ARGUM.	GROUP N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPLIT. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.
105-139	65	Q1	6.837	.084	1.1510	.0141	-2.252	.707
143-149	26	O1	35.591	.087	1.1472	.0028	-.678	.140
152-158	22	NO1	2.826	.102	1.1584	.0420	2.162	2.076
161-163	10	P1	16.067	.097	1.1128	.0067	2.386	.345
164-168	23	K1	49.530	.090	1.1353	.0021	.937	.104
172-177	22	J1	2.694	.087	1.1044	.0357	-1.409	1.852
181-1I3	37	OO1	1.665	.059	1.2454	.0443	1.842	2.017
207-23X	41	2N2	.938	.032	.9317	.0321	11.575	1.961
243-248	24	N2	8.000	.053	1.0521	.0069	13.401	.377
252-258	26	M2	45.524	.050	1.1462	.0012	10.464	.062
262-267	17	L2	1.373	.024	1.2228	.0217	6.343	1.016
271-273	6	S2	22.745	.044	1.2309	.0024	7.523	.110
274-2X5	41	K2	6.023	.034	1.1980	.0068	9.503	.323
327-375	17	M3	.541	.027	.9527	.0470	-2.596	2.798
382-382	1	S3	.2945	.0269				
455-455	1	M4	.0617	.0168				
491-491	1	S4	.1168	.0151				

STANDARD DEVIATIONS D .92 SD .42 TD .25 QD ..14

Table 2.a. OVIEDO 1, RESIDUALS MODEL 1

DISTRIBUTION OF ΔU FOR SD

i	INTERV.	n_i	χ^2
	$-\infty$		
1	-11.7250	11	.01
2	-6.6296	15	1.22
3	-2.7210	6	2.48
4	.9591	8	.96
5	4.8677	13	.26
6	9.9631	14	.65
7	$+\infty$	12	.05

n = 79 χ^2 = 5.62

CRIT.VALUE OF χ^2 = 11.07

DISTRIBUTION OF ΔV FOR SD

i	INTERV.	n_i	χ^2
	$-\infty$		
1	-8.9492	15	1.22
2	-4.8263	11	.01
3	-1.6637	7	1.63
4	1.3140	7	1.63
5	4.4766	14	.65
6	8.5995	18	3.99
7	$+\infty$	7	1.63

n = 79 χ^2 = 10.76

CRIT.VALUE OF χ^2 = 11.07

Table 2.b. OVIEDO 1, RESIDUALS MODEL 2

DISTRIBUTION OF ΔU FOR SD

i	INTERV.	n_i	χ^2
	$-\infty$		
1	-19.6657	16	1.97
2	-13.9597	8	.96
3	-9.5825	10	.15
4	-5.4615	7	1.63
5	-1.0844	13	.26
6	4.6217	13	.26
7	$+\infty$	12	.05

n = 79 χ^2 = 5.27

CRIT.VALUE OF χ^2 = 11.07

DISTRIBUTION OF ΔV FOR SD

i	INTERV.	n_i	χ^2
	$-\infty$		
1	-7.0763	15	1.22
2	-3.4506	6	2.48
3	-.6694	13	.26
4	1.9491	3	6.08
5	4.7302	19	5.27
6	8.3559	15	1.22
7	$+\infty$	8	.96

n = 79 χ^2 = 17.49

CRIT.VALUE OF χ^2 = 11.07

Table 3. Coefficients b_1, b_2, b and β determined by different D filters, N = length of the filters, k = eliminated power.

FILTERS		Oviedo 1, residuals model 1				
N	k	b_1	b_2	m.s.e.	b	β
36	1	.407	.209	±.065	.458	27°2
36	2	.218	.012	.071	.218	3.2
42	1	.319	.205	.072	.379	32.7
42	2	.303	.223	.072	.376	36.3
48	1	.344	.193	.075	.394	29.3
48	2	.348	.197	.076	.400	29.5

FILTERS		Oviedo 1, residuals model 2				
36	1	1.567	.957	±.049	1.836	31°4
36	2	.385	.084	.076	.394	12.4
42	1	1.522	.978	.051	1.809	32.7
42	2	1.513	1.012	.059	1.820	33.8
48	1	1.536	.968	.052	1.815	32.2
48	2	1.539	.964	.052	1.816	32.1

FILTERS		Oviedo 2, residuals model 2				
36	1	.090	.010	±.040	.091	6°4
36	2	.024	.023	.106	.033	43.9
42	1	.121	-.025	.041	.124	-11.5
42	2	.101	.020	.040	.103	10.9
48	1	.017	-.006	.042	.018	-20.5
48	2	.018	-.015	.042	.024	-40.8

Note: The unit of the coefficients b_1, b_2 and b is $\mu gal/{}^{\circ}C$

Table 4. Coefficients b_1, b_2, b and β determined by D, SD, TD and QD filters, N=36, k=1.

FILTERS	Oviedo 1, residuals model 1				
N=36, k=1	b_1	b_2	m.s.e.	b	β
Diurnal	.407	.209	±.065	.458	27°.2
Semi Diurnal	.661	.746	.133	.997	48.5
Ter Diurnal	.609	-.197	.135	.640	-17.9
Quarter Diurn	.283	.027	.082	.284	5.4

FILTERS	Oviedo 1, residuals model 2				
Diurnal	1.567	.957	±.049	1.836	31°.4
Semi Diurnal	.710	.732	.135	1.020	45.9
Ter Diurnal	.593	-.202	.136	.626	-18.8
Quarter Diurn	.283	.027	.082	.284	5.4

FILTERS	Oviedo 2, residuals model 2				
Diurnal	.090	.010	±.040	.091	6°.4
Semi Diurnal	.147	.151	.067	.211	45.6
Ter Diurnal	.522	.536	.087	.748	45.7
Quarter Diurn	.045	-.163	.083	.169	-74.6

Note: The unit of the coefficients b_1, b_2 and b is μgal/°C

Ground Water Effects on Borehole Tilt Measurements

A. Weise*

1. Introduction

The three component station in Metsähovi / Finland near Helsinki is described in Alms et al. (1989, 1990), giving the results of tidal analyses in tilt and gravity. The tidal tilt parameters are in very good agreement with the results of the long water tube tiltmeters in the mine in Lohja, at a distance of some 15 km (Käärläinen, 1979 and Kääriäinen & Ruotsalainen, 1989).

Usually tilt records are considered as very noisy because of the sensitivity to meteorological effects as ground water and airpressure, disturbing the tides and the drift signal. In the record of the ASKANIA - borehole - tiltmeter P7 in Metsähovi a number of non-tidal signals of some milliseconds can be correlated with ground water variations. Some reproduceable characteristic examples will be classified in amplitude and in time. In order to prove these findings first physical models will be presented.

The observatory Metsähovi is situated in an area of granite without mayor faults. The tiltmeter is installed in a 63 m deep borehole (fig. 1). A water bearing layer in the depth of 43 m is dipping with 20° to the north west. In an additional borehole, some 4 m from the tiltmeter, the water level is rising until 6 to 8 m below the surface. The water column is reproducing the porepressure variations in the aquifer, caused by pumping under the observatory, besides natural variations.

Tides are not really proved in the ground water level. The Fourier spectra show signals of varying amplitudes in the tidal frequency bands, which are effects of the perturbations by pumping. Obviously the aquifer is not ideally confined.

Long periodic variations of the ground water level, caused by rain-fall, melting snow or seasonal changes, with periods greater than several hours, are directly representing the porepressure. The influence on the tilt is a very small long periodic drift, hardly to be recognized in the record.

The subject of this paper will be the short periodic abruptly starting ground water effects on the tilt record (fig. 2a, b).

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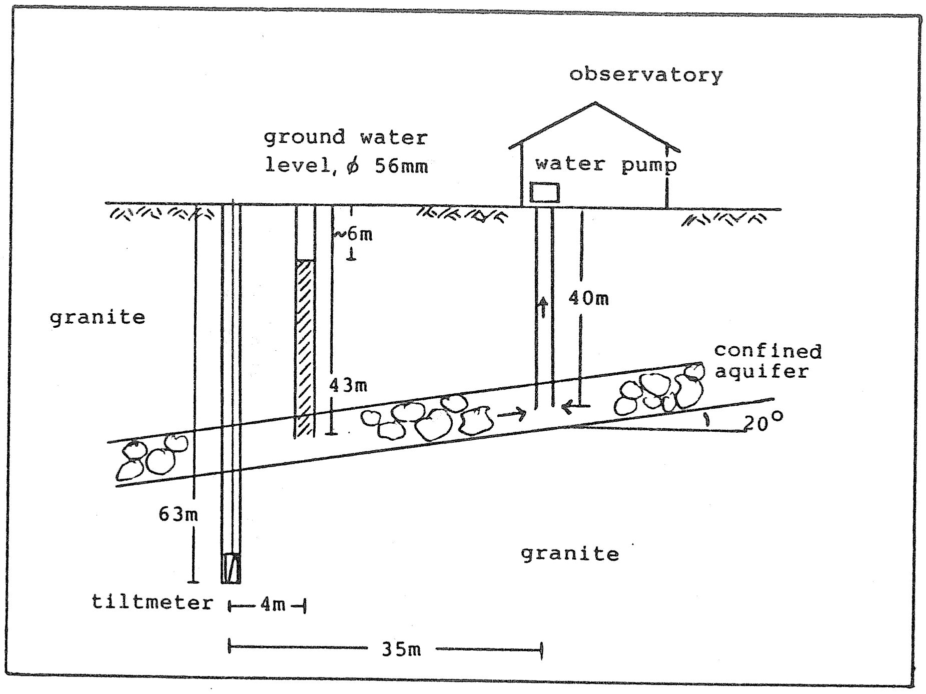


Figure 1: The location of the station Metsähovi / Finland

2. Observed ground water effects in the tilt record

Typical examples of the short periodic ground water effects are given in figures 2a and 2b for the tilt components X and Y, X nearly orientated in direction to the pump (X: 168°N, Y: 258°N). Two perturbations in the tidal records are shown in their real characteristic (9 and 6 msec), when the tides are removed. The decay takes nearly one day. The ground water level drop is in the range of 95 and 68 cm.

The abruptly starting porepressure variations with periods up to some hours are caused by pumping near the tiltmeter station. The ground water level in the borehole is giving the porepressure changes, frequency depentent with a certain time delay and damping of the amplitudes. These "man made" effects are usually intended to be avoided. Nevertheless, they contain some informations about the very local geological situation.

Kümpel (1989) carried out pumping tests in sediments in northern Germany, producing tilt signals of 30 to 100 msec. While in our case, the signals of 5 to 10 msec are smaller but clearly distinguishable from other geological and instrumental effects.

The two - dimensional plots of the tilt variations during the ground water events (fig. 3) are very similar in the shape of their figures, giving the characteristic of the process with a very high resolution. If the underground material was totally homogeneous, the tilt signal caused by pumping is expected to move in the direction of the highest porepressure gradient, that is in direction to the pump, and finally to move

Figure 2a: Metsähovi : tiltmeter P7 - X-component 88.05.11 0h - 88.05.17 24h

influence of ground water level variations

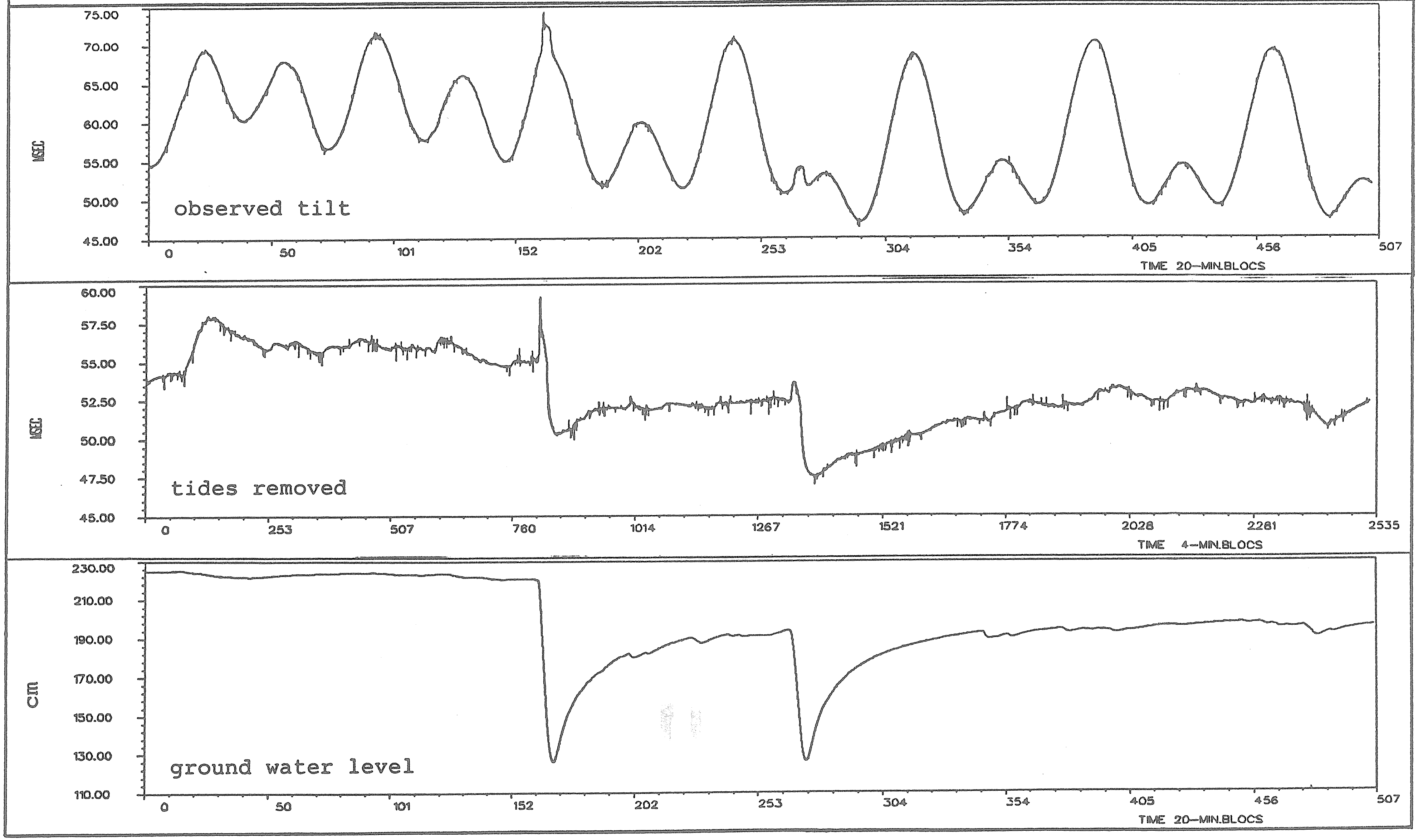
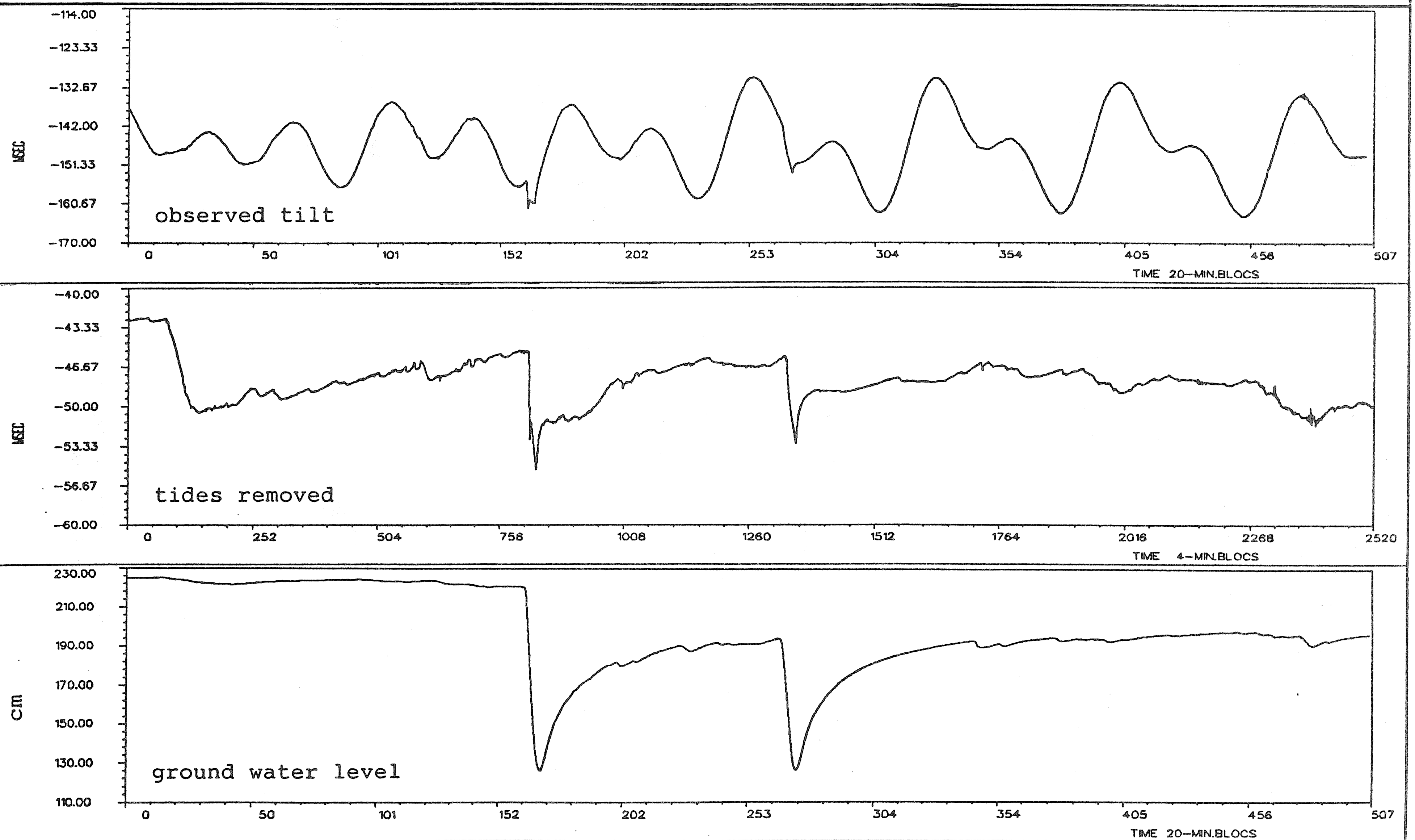


Figure 2b: Metsähovi : tiltmeter P7 - Y-component 88.05.11 0h - 88.05.17 24h
influence of ground water level variations



back the same way. The direction to the pump under the observatory building has an azimuth of about 190°N. On the other hand the observed trace of the signal is describing a rotation in the order of 5 to 10 msec and even 30 msec, which is usually after one day more or less returning to the starting position. In detail the similarities are:

- The trace is starting in a circle, finally changing into a linear trend with an azimuth of about 45°.

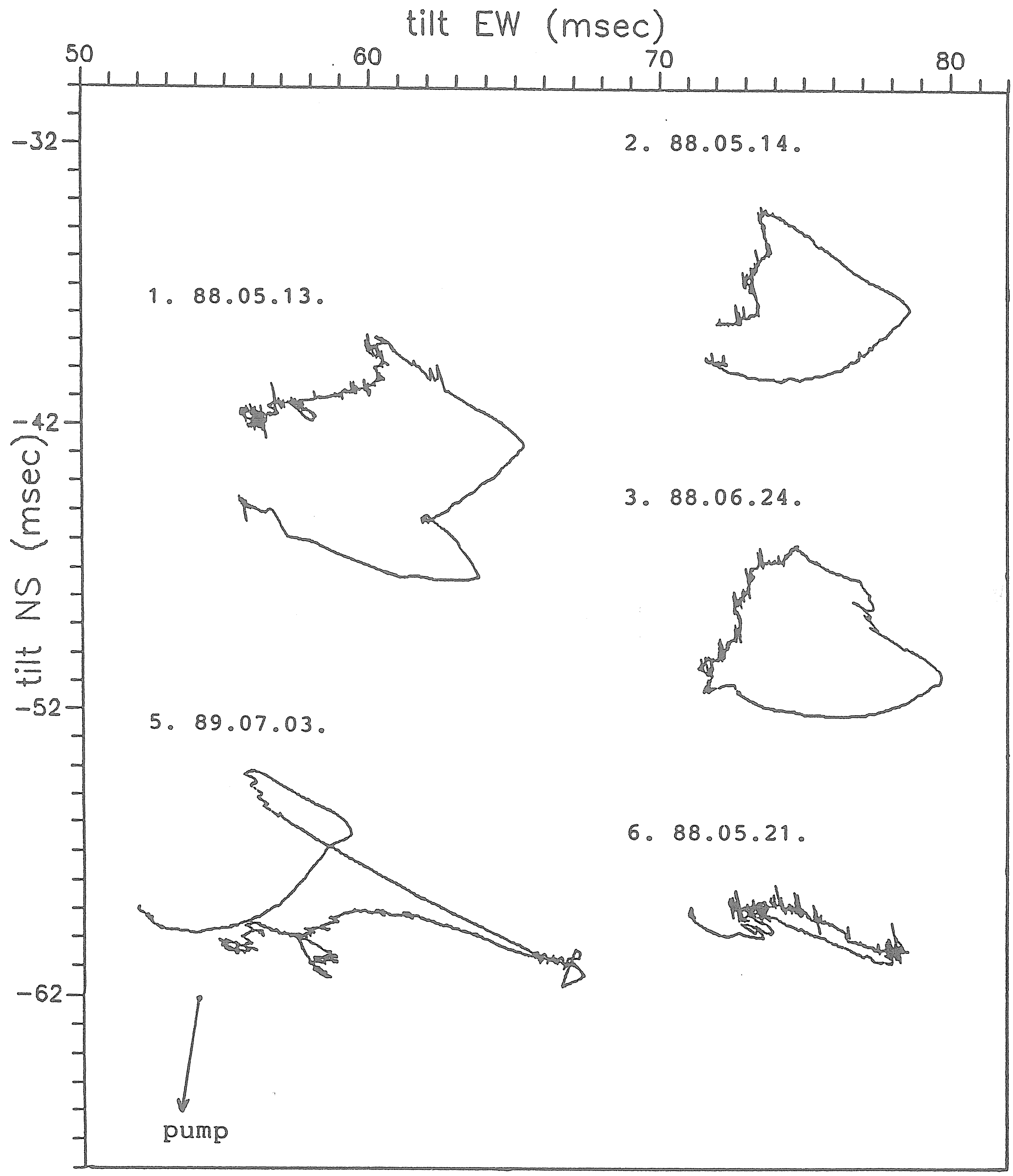
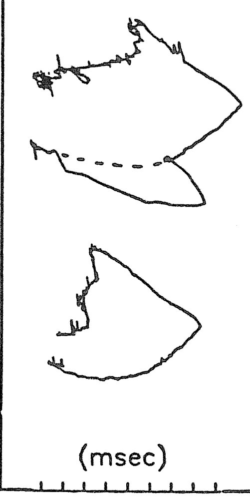


Figure 3: 2D-plots of some porepressure induced tilt signals, sample rate: 20 seconds, tides removed

- The turning point after 80 to 100 minutes or even later is taking place, when the pumping stops. The ground water in the borehole is still dropping, while the gradient of the water level just in this moment is decreasing abruptly (see fig. 4).
- Continuing nearly in the normal direction of ≈305° is another dominant direction, corresponding with the dipping direction of the water bearing layer.
- Nearly one hour after the minimum of the water level the trace is turning again, in direction to the starting point. If a further perturbation is occuring, it is in the mentioned dominant direction of ≈305° or to the opposite direction ≈125°, respectively, as the last two examples in figure 3 show.
- The velocity of the tilt variation is rather fast. The movement back, after the second turning point becomes very slow, as the recovery process of the porepressure.
- The coupling of tilt and ground water signal is obvious on the first sight. A fix amplitude ratio could be found between the trace of the pendulum until the first turning point (in msec.) and the amount of the drop of the water level (in cm), which is reached later. Table 1 gives the factors for six examples. The mean factor is 0.115 msec/cm, which is valid only if a perturbation during the event is corrected, that means reduced to an ideal trace (example 1, dashed line in table 1).

Table 1: Amplitude ratio between the trace of the tilt (msec) and the drop of the ground water level (cm). (* = estimated amount of water level drop because of exceeded measuring range)

no.	date	h_p - drop gr.water (cm)	tilt N raw (msec)	tilt N correct. (msec)	factor f N/h_p (msec/cm)	
1	88.05.13	94.6	15.1	10.5	0.111	
2	88.05.14	67.6	8.0	-	0.118	
3	88.06.24	65.6	7.3	-	0.111	
4	89.04.15	350.0 * 330.0 *	37.9 37.9	- -	(0.108) 0.115	
5	89.07.03	92.7	10.9	-	0.118	
6	88.05.21	19.5	2.3	-	0.118	
				mean:	0.115 ±0.002	

- The mechanism becomes more clear with figure 5. For two exeamples the gradient of the ground water record is drawn over the (tides removed) tilt rate, independent from the tilt direction. It is proved that the tilt is reacting on the porepressure variation 10 to 20 minutes in advance of the water level in the borehole. The tilt gradient reaches a maximum at the beginning of the event, decreasing to a nearly constant "speed" until the stop of the pumping process. The velocity of the tilt signal increases again for some minutes with the abrupt drop in the gradient of the water level. Subsequently the tilt gradient decreases smoothly with the porepressure.

The observed tilt signal is proved to reproduce the porepressure variations during and after the fluid extraction. Extremly small events in the order of 0.5 msec, taking less than one hour, even show the described characteristic (fig. 4), although there is no signal in the ground water record. They can be produced by very short term pore pressure variations by pumping water, while the water level in the borehole is a filtered and damped signal, recorded with a sample rate of 10 minutes.

The found significant characteristics will be introduced in the development of a model about the ground water effect in tilt measurements.

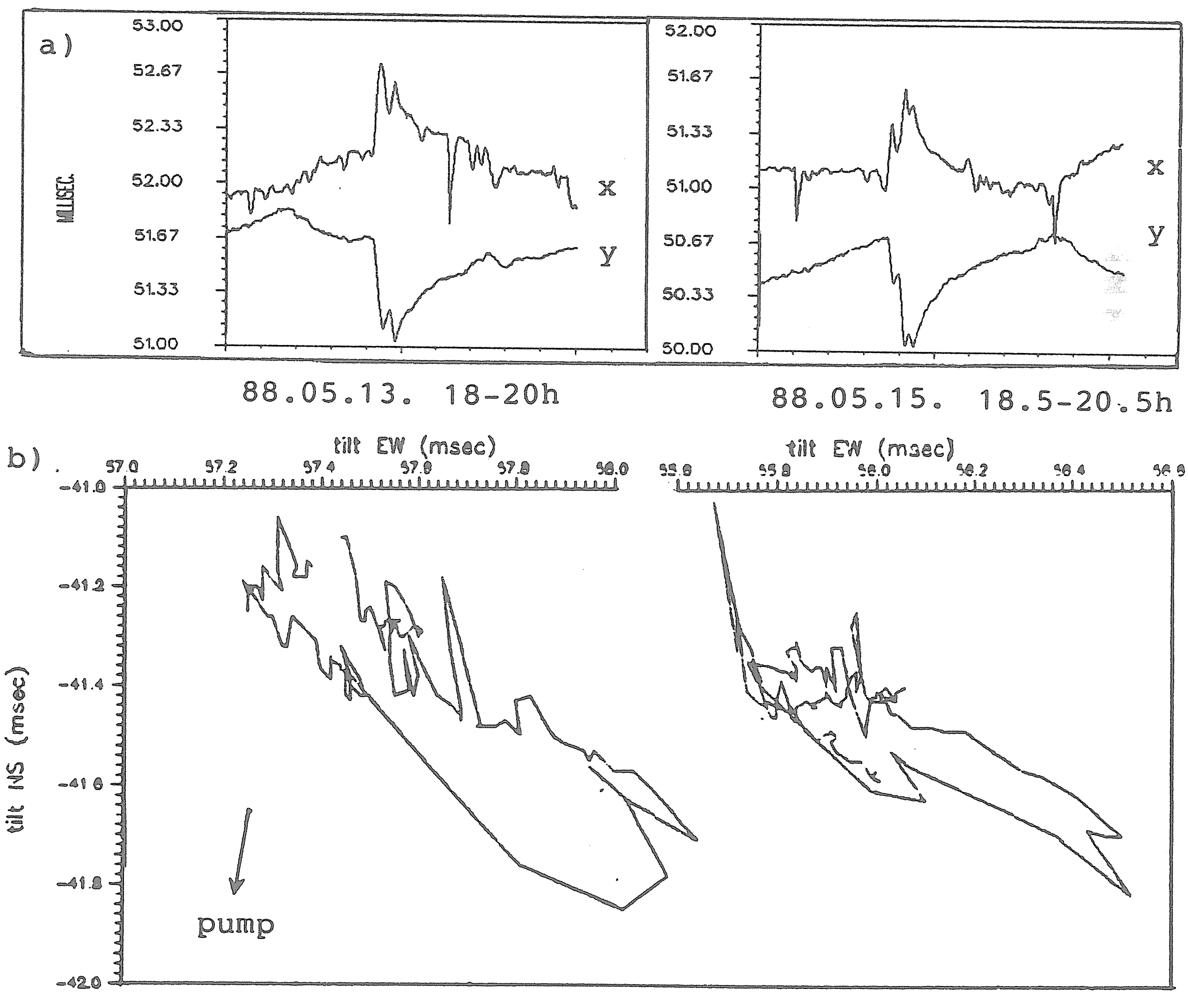


Figure 4: Very small tilt signals ≤ 0.5 msec, sample rate: 20 seconds
a) X, Y-components, orientation: X: 168°N, Y: 258°N,
b) 2D-plots

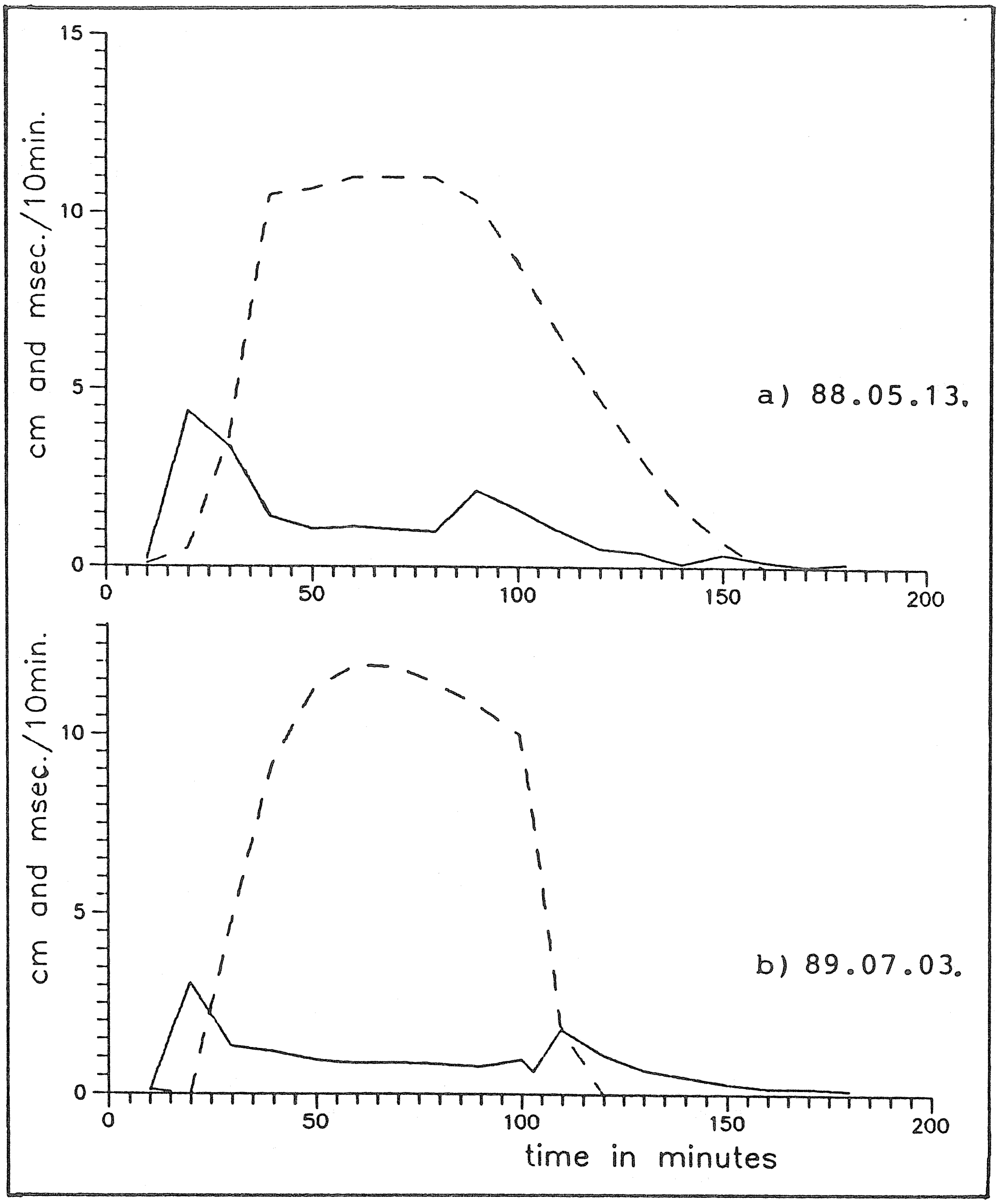


Figure 5: Gradient of ground water level (- - -) in cm/10 min. and tilt rate (———) in msec/10 min; a) 88.05.13. ; b) 89.07.03.

3. Modelling ground water effects (shear deformation)

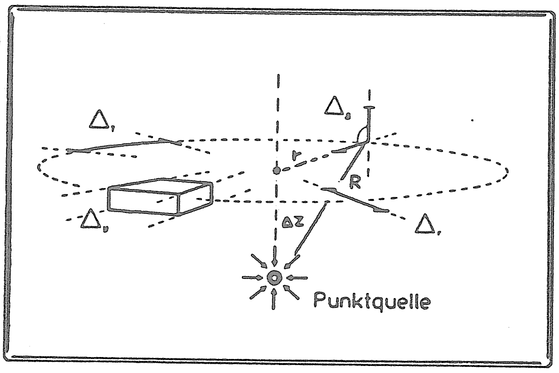
The porepressure induced tilt variation is equivalent to the shear deformation, restricted to the vertical plane which is mounted by the tiltmeter and the well (fig. 6). Kümpel (1989) gives the model for the extended linear poroelastic theory, basing on Biot (1941) and Rice & Cleary (1976). Isotrop and homogeneous medium is assumed. The main parameters are:

- geometric parameters: distance r, depth z between well and tiltmeter
- water volume V or the production rate Q, respectively, and the
- diffusivity D: a characteristic of the recovery rythm of the pore-pressure after a natural or forced alteration, dependent on the
- rockparameters: poisson ratio ν, poisson ratio under undrained conditions ν_u, permeability æ, shear modulus G and Skempton's porepressure paramter B.

The order of magnitude valid for granite and the units are given in figure 6.

Kümpel (1989) received diffusivities for sand in the range of 1000...7000 cm²/sec. From the recovery process of the water level in Metsähovi, mean values of 500...1500 cm²/sec are derived within the aquifer. There are indications to varying diffusivity or permeability during the recovery process of the water level.

Figure 6: Parameters of shear deformation Extended Linear Poroelastic Theory (Kümpel, 1989)



geometric:	distance	r	[m]	
	depth	Δz	[m]	
injection:	volume	V	[m³]	
	rate	Q	[m³/h]	
rock-parameters:	diffusivity D	$D = \frac{2(1-\nu)(1+\nu_u)^2}{9(1-\nu_u)(\nu_u-\nu)}$ æ G B²		[cm²s⁻¹]
	poisson number	ν	(0.25...0.27)	
	poisson number, undrained conditions	ν_u	(0.30...0.34)	
	permeability	æ = k/η		[m³s kg⁻¹]
	intrinsic permeability	k	(1...20 10^{15})	[cm²]
	dynamic viscosity of porefluid	η	(0.012 poise)	[Pa s]
	shear modulus	G	(15...19 GPa)	[Pa]
	Skemton's porepressure parameter	B	(0.55...0.90)	

Modelling shear deformation, three basic processes are distinguishable according to the type of injection or extraction of a certain fluid volume:

1. Impuls - like injection: the whole volume is injected at one moment
2. Constant injection rate of a volume per hour and
3. Exponential decreasing injection rate

Injection into a medium and extraction are causing the same amplitudes of porepressure changes in opposite direction, that means with opposite sign.

Using some realistic parameters for granite, a number of model calculations are carried out, according to the location of the station Metsähovi.

For the extracted water volume, realistic values are chosen, for example 5 liters for the impuls - like injection. This leads to a tilt effect of 0.8 msec (fig. 7.1), just in the order of the very small observed events in figure 4. Varying the diffusivity in realistic order of magnitude, a number of model functions for the shear deformation are obtained. A high diffusivity means a fast recovery process of a changed porepressure, for example in sand. This fact is reflected in the modelled tilt variations.

The case of constant injection rate is more realistic according to longer pumping processes (fig. 7.2). Lower diffusivity is causing higher tilt amplitudes. The model curves of 0.8...2 msec refer to an extraction rate of 10 liter/hour, entering the formulas as a linear amplification factor. A pumping rate of 100 l/h can produce tilt signals of 20 msec.

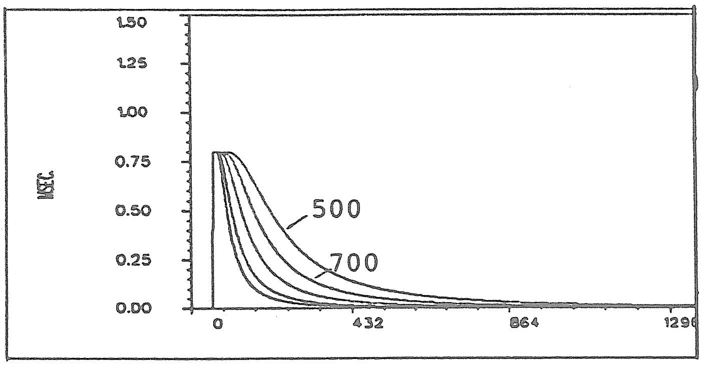
The last model curve is basing on the fact, that the abrupt stop of water pumping is producing a new process of porepressure variation, but in the opposite direction. Both processes can be summed up with a certain time delay, producing again a peak of 0.8 msec (fig. 7.4). If during the second process the conditions as injection rate or diffusivity change, the model function will not tend towards zero but will end at a certain offset, due to this change.

Finally figure 8a shows again some model deformations with a time delay of 92 minutes between begin and end of the pumping, a pumprate of 100 l/h assumed. For realistic diffusivities peaks between 7 and 17 msec are reached. Gradients from these model functions in figure 8b show again two maxima, each at the start of the two added processes of porepressure change, analogous to the observed tilt rates in figure 5.

4. Conclusions

The quantitativ agreement of observed and modelled tilt deformation in the general structure and in the order of magnitude confirm the validity of the linear poroelastic theory as a first approach. Even very small porepressure induced tilt signals in the order of 0.5 msec agree with the model, proving the very high resolution and confidence of the tilt records. The reason of the observed change of the direction during the abrupt end of the pumping can be produced by non-isotrop permeability, that means the permeability is dependent from the direction, possibly caused by orientated clefts, in connection with the dip direction of the aquifer.

1. <u>impuls- like injection</u>



injection volume: -5 l

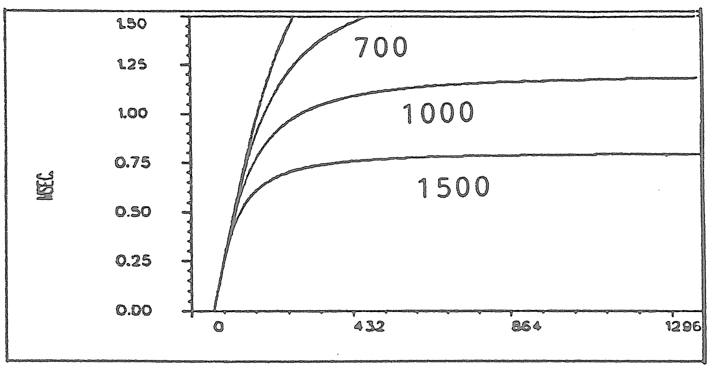
diffusivity:
500,700,1000,1500,2000 cm^2s^{-1}

distance: 35 m

depth :-20 m

⟼ 30 minutes

2. <u>constant injection rate</u>

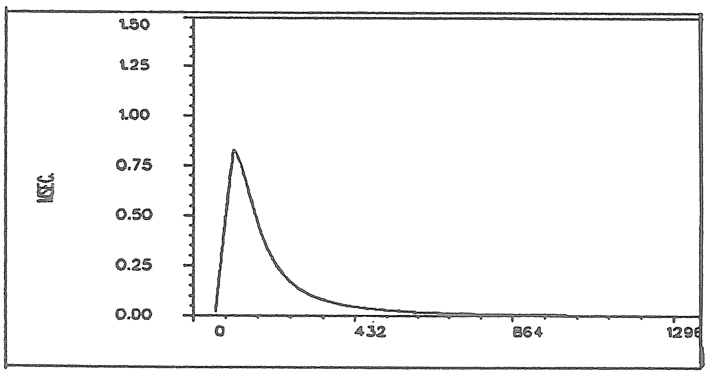


injection rate: -10 l/h

diffusivity:
500,700,1000,1500 cm^2s^{-1}

3. <u>exponential decreasing injection rate</u>

4. <u>constant injection rate (additive)</u>



injection rate: a) -20 l/h
+20 l/h

diffusivity: 1000 cm^2s^{-1}

time delay : 16 minutes

Figure 7: Model functions of shear deformation with:
porepressure parameter B = 0.80 , poisson ratio ν = 0.24 ,
poisson ratio undrained ν_u = 0.30

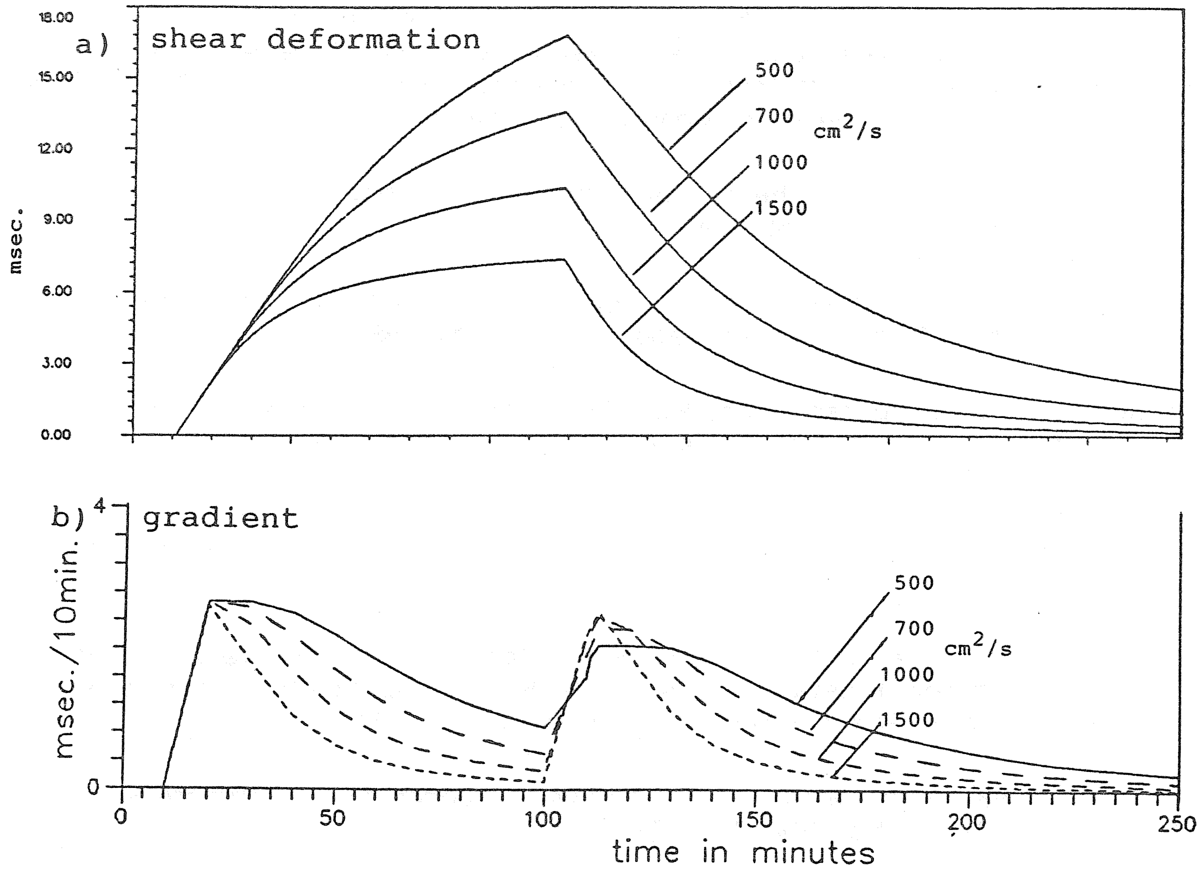


Figure 8: a) Model functions of shear deformation for various diffusivities with pump rate Q=100 l/h and time delay dt=92 min.
b) Gradient functions from a) in msec/10 min.

5. Acknowledgements

The "Bayerische Kommission für die Internationale Erdmessung der Bayerischen Akademie der Wissenschaften" in Munich made available the ASKANIA - borehole - tiltmeter no. 7. The tiltmeter was maintained by H. Ruotsalainen from the Finnish Geodetic Institute, which also made the borehole available. All this is gratefully acknowledged.

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A check of the calibration factors of five LaCoste-Romberg mod. G. gravimeters used for tidal gravity measurements.

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The present investigation has been made to validate the data obtained during the Trans World Tidal Gravity profiles in 131 temporary stations included in the ICET Data Bank.
Minor revisions of the data processing have already been made accordingly; results will be made available soon.

The problem of the calibration of astatized gravimeters used for tidal observations has been often considered since several years. One reason is, of course, that the successful comparison of the observed oceanic indirect effects with the corresponding effects (attraction + loading + potential change) calculated with a Farrel procedure on the basis of the Schwiderski cotidal maps has raised much interest in view for the interpretation of the residues.
The fact that a number of final residues remain higher than the noise level of the observations could suscitate some suspicion on the accuracy of the calibration factor of the instrument at a level of 1 % or, possibly, better.

The classical spring gravimeters (e.g. LaCoste Romberg used here) which measure differences of gravity but not gravity are delivered by their makers with a calibration factor K (which may slightly vary in function of the screw dial) which is expressed with three decimals and was determined by additions of small masses on the beam and / or by observations along a local baseline. We have no information about the accuracy of these determinations. In the case of our five LaCoste Romberg instruments, this factor K varies from one to another gravimeter from 1.004 to 1.064 which means that the reading of the dial has to be multiplied by this factor to express micrometric differences in microgals. These calibration factors which may be correct to about 0.05 % can be checked by transporting the gravimeter along specific gravity baselines.

Since 1980 we have used our instruments in Asia, Africa and South America (Table I) along profiles involving large differences of gravity : up to 4 gals.
However, due to the necessities of transportation, these instruments were never used to determine the gravity differences with respect to the starting point Bruxelles Airport. They were transported clamped evidently but also the heating was interrupted. Each transportation could take 2 days before the instrument was put again into heating. Successive transfer of the equipment to a next station was made after six months of tidal registration.

Nevertheless, for checking the micrometer and the instrumental drift, we consider the micrometer reading just before departure from one station and the micrometer reading just after installation at the next station in order to compare the micrometric difference with the difference of gravity when available. The results are given in the tables which follow. They are compared with the maker's calibration coefficient.

Despite a drift ΔM of the order of one half to one milligal (seldom 2 milligals) during the six months of observations, the results are unexpectedly excellent and we can even consider micrometric readings taken at five years interval in the cases where dg reaches 1 gal or more as shown, for example, by the Bruxelles (1976) - Mizusawa (1981) connection obtained with the gravimeter LCR G402 : $dg/dM = 1.05988$ while the maker's coefficient is 1.062 (absolute values of g are known at these two stations).
The tables show that the maker's coefficients are correct to about 0.5 %. However it is not sure if the calibration factor determined in this way, from very large gravity differences can be used for tidal variations of g which do not exceed 0.3 milligal. As a matter, of fact we had to decide to correct them by about 0.5 % (in + or in -, depending on the instrument) on the basis of comparisons of the amplitude of the tidal diurnal wave O1 obtained from several months of comparative registrations between many instruments at Bruxelles, Wuhan (China), Curitiba (Brazil) and Canberra (Australia).

In the tables the micrometric readings M are expressed in units of the dial while g is given in milligals for differential measurements (one *) and in microgals when it was obtained from absolute measurements (two *). The ratio dg/dM is given with four decimals when dg is more than one gal.
The letter Z indicates that the instrument was transformed into a zero method instrument.

The value of g was not known at several stations and has been calculated on the basis of the micrometric difference with respect to Bruxelles (noted C).
From the results shown in the following tables, it seems that the maker's calibration factor has to be

decreased (0.5%) for LCR 003 :	K	=	1.036
unchanged for LCR 008 :	K	=	1.004
decreased (0.5%) for LCR 336	K	=	1.059
unchanged for LCR 402 :	K	=	1.062
probably increased (0.7%) for LCR 906	K	=	1.025

Since 1973 fourteen different LaCoste Romberg gravimeters have been installed in the underground gravimetric room of the Royal Observatory in Bruxelles for periods of registration of 3 to 6 months.
To adjust the δ (O_1) factor to its value adopted for Bruxelles in 1973 : 1.1610, we had of course to multiply the LaCoste Romberg calibration values K of each instrument by a factor F always very close to unity.
The mean value of the fourteen adjustements is

$$F = 0.99172 \pm 0.00744$$

Remarks about the instrumental drift

Gravimeter LCR 003 has an irregular drift of about 1 milligal within six or eight months.

Gravimeter LCR 008 has no drift at all : after four years measurements in Brazil (1983-1987) and its transformation into zero method during its installation at Curitiba the micrometric reading at Bruxelles station differs by only one milligal. Later on, in Algeria, there was also no drift.

These two instruments are about 40 years old and this may explain their stability.

Gravimeter LCR 336 (delivered in 1973) is not as stable as the old ones : the drift can reach 2 milligals within six months and can be negative as well as positive but, as shown by the micrometric readings M at Bruxelles, its long term drift is essentially positive :

epoch	M	M
1982/11	4555.65	
1983/10	4558.15	+ 2.50
1986/06	4559.30	+ 1.15
1989/08	4560.90	+ 1.60

However its calibration factor is extremely stable so that the same value has been used for all stations since the very beginning (F = 0.99449).

Gravimeter LCR 402 (delivered in 1975) behaviour is similar to LCR 336, exhibiting a drift up to 2 milligals during each period of six months tidal measurements, alternately positive and negative so that the micrometric readings at Bruxelles were invariable in seven years but suddenly increase during the last eight years

epoch	M
1976/06	4603.80
1979/06	4603.80
1983/12	4603.79
1991/08	4606.00

Gravimeter LCR 906 (delivered in 1987) is a "young" instrument so that no definitive conclusion can be given now about its stability

TABLE I

LCR Gravimeters	used abroad since		with null method since	
G 003	november	1973	july	1984
G 008	july	1975	july	1984
G 336	august	1974	october	1983
G 402	june	1976	january	1984
G 906	september	1988	septembre	1988
D 32	september	1980	october	1984

Table 2 Control of calibrations for LaCoste Romberg gravimeters

Instrument	Using absolute values of g		Using differential values of g	Maker (K)	Analyses (KF)
003	Bruxelles-Viçosa	1.0419			
	Viçosa-Curitiba	1.0359			
		------	5 values		
		1.0389	1.0343 (w)	1.041	1.029
008	Viçosa-Bruxelles	1.0012			
	Bxlles-Curitiba	1.0013			1.0046
		------	9 values		1.0065
		1.00125	1.0040 (w)	1.004	1.0017
336	-		7 values		
			1.0548 (w)	1.065	1.0591
402	Bxlles-Mizusawa	1.0599			
	Bxlles-Caracas	1.0621			1.071
		------	11 values		1.046
		1.0610	1.0622 (w)	1.062	1.062
906	Bxlles-B.Aires	1.0204			
	B.Aires-Tacuar.	1.0301	-		

		1.0252		1.018	1.035

w weighted

LCR 003 - 003 Z

Maker calibration factor K= 1.041

CONNECTIONS	M=Micrometer	g,dg	dg/dM	M(drift)
Stellenbosch - Bruxelles	2074.40	979631*		
82/11 83/05	3533.09	981117**		
	+ 1458.69	+ 1486	1.0187*	
BRAZIL				
Bruxelles - Vicosa	3533.45	981117.272**		+0.36
83/10	0983.15	978460.230**		
	- 2550.30	- 2657.042	1.0419**	
Vicosa - Curitiba	0983.55	978460.230**		+0.40
84/04	1273.30	978760.387**		
	+ 289.75	+ 300.157	1.0359**	
Curitiba - C.Grande Z	1272.15	978760**		-1.15
84/11	1020.75	978495*		
	- 251.40	- 265	1.054*	
C.Grande - Manaus Z	1019.50	978495*		-1.25
85/07	0544.50	978006*		
	- 475.00	- 489	1.029*	

Stellenbosch - Manaus 82/11 85/07	- 1529.90	- 1625	1.0622*
Stellenbosch - Bruxelles 82/11 83/05	+ 1458.69	+ 1486	1.0187*
Bruxelles - Manaus 83/10 85/07	-2988.95	-3111	1.0408*
	Weighed mean	(6.2 gal)	1.0411
Two absolute connections		Mean	1.0389
Five connections -	Weighed mean	(5.2 gal)	1.03432

Results for the period 1973-1976

1) by micrometric differences:

		dg	dg/dM
73/11	Bruxelles - Manila	2767	1.0549
75/03	Port Moresby - Canberra	1375	1.0534
76/05	Charters T. - Canberra	1001	1.0380
76/12	Canberra - Bruxelles	1547	1.0408
	Weighed mean		1.0488

2) by measurements on local polygons

Townsville	1.0413
Canberra	1.0388
	1.0401

LCR 008 - 008 Z

Maker calibration factor K= 1.004

CONNECTIONS		M=Micrometer	g,dg	dg/dM	ΔM(drift)
BRAZIL					
Bruxelles - C.Grande		4698.20	981117**		
83/11		2080.30	978495*		
		- 2617.90	- 2622	1.0016*	
C.Grande - Curitiba		2080.64	978495*		+0.34
84/04		2344.47	978760**		
		+ 253.83	+ 265	1.044*	
Curitiba - Caico	Z	2344.47	978760**		0
84/11		1633.25	978033*		
		-711.22	- 727	1.022*	
Caico - Salvador	Z	1633.25	978033*		0
85/07		1898.85	978311*		
		+ 265.60	+ 278	1.047*	
Salvador - Vicosa	Z	1898.50	978311*		-0.35
86/05		2043.25	978460**		
		+ 144.75	+ 149	1.031*	
Vicosa - Bruxelles	Z	2043.25	978460.230**		0
87/08		4697.20	981117.272**		
		+ 2653.95	+ 2657.042	1.0012**	
AFRICA					
Bruxelles - M'Bour	Z	4697.20	981117**		
87/10		1951.30	978370*		
		- 2745.90	- 2747	1.0004*	
M'Bour - Alger	Z	1951.30	978370*		0
88/05		3479.70	979897*		
		+ 1528.40	+ 1527	0.9991*	
Alger - Tamanrasset	Z	3479.70	979897*		0
88/12		2014.80	978435*		
		- 1464.90	- 1462	0.9980*	

Nine connections - Weighed mean (12.4 gal) 1.00399

Bruxelles - Curitiba	2353.73	2356.885	1.0013**
Bruxelles - Caico	3064.95	3077	1.0039*

Results for the period 1975-1976

1) by micrometric differences:

		dg	dg/dM
75/11	Canberra - Hobart	847	1.0005
	Hobart - Canberra	847	1.0006
76/05	Canberra - Lauder	949	1.0007

2) by measurements on local polygons

Canberra	1.0004
Hobart	1.0017
	1.0011

LCR 336

Maker Calibration Factor K= 1.0605

CONNECTIONS	M=Micrometer	g,dg	dg/dM	ΔM(drift)
AFRICA				
Nairobi - Voi 80/11	1154.30 1511.30	977514* 977884C		
	+ 357.00	+ 370	1.037	
Voi - Addis Ababa 81/05	1511.30 1098.99	977884C 977431*		0
	- 412.31	- 453	1.098	
Addis Ababa - Djibouti 81/10	1099.65 1680.95	977431* 978024*		+0.66
	+ 581.30	+ 593	1.020*	
Djibouti - Butare 82/05	1681.35 1202.60	978024* 977546C		+0.40
	- 478.75	- 478	1.000	
Butare - Bruxelles 82/11	1203.90 4555.65	977546C 981117**		+1.30
	+ 3351.75	+ 3571	1.065	
Bruxelles - Avignon 83/03	4555.75 3974.45	981117** 980499C		+0.10
	- 581.30	- 618	1.063	
Avignon - Bruxelles 83/10	3973.80 4558.15	980499C 981117**		-0.65
	+ 584.35	+ 618	1.058	
Bruxelles - Niamey 84/01	4558.15 1868.00	981117** 978262*		0
	- 2690.15	- 2855	1.0613*	
Niamey - Arlit 84/06	1868.55 2013.30	978262* 978407C		+0.55
	+ 144.75	+ 145	1.000	
Arlit - Bangui 85/02	2015.30 1522.20	978407C 977900*		+2.00
	- 493.10	- 507	1.028	
Bangui - Brazzaville 85/12	1520.35 1553.55	977900* 977947*		-1.85
	+ 33.20	+ 47	[1.4]	
Brazzaville - Bruxelles 86/06	1554.20 4559.30	977947* 981117**		+0.65
	+ 3005.10	+ 3170	1.0549*	
Bruxelles - Kedougou 87/10	4560.90 1856.40	981117** 978279*		+1.60
	- 2704.50	- 2838	1.0494*	
Kedougou - Bamako 88/06	1857.30 1801.90	978279* 978190*		+0.90
	- 55.40	- 89	[1.6]	

./...

Bamako - Nouakchott	1801.00	978190*		-0.90
89/03	2161.80	978572*		
	+ 360.80	+ 382	1.059*	
Nouakchott - Bruxelles	2162.05	978572*		-0.90
89/08	4560.90	981117**		
	+ 2398.85	+ 2545	1.0609*	
Bruxelles - Lanzarote	4563.40	981117**		+2.50
90/04	2962.65	979428*		
	1600.75	- 1689	1.0551*	
Seven Connections -	Weighed mean (14.1 gal)		1.0548	

Results for the period 1974-1976

1) by micrometric differences:

		dg	dg/dM
74/05	Bruxelles - Sèvres	191	1.0652
	Sèvres - Bruxelles	191	1.0610
75/06	Canberra - Perth	139	1.0710
75/11	Perth - Darwin	1123	1.0531
76/04	Darwin - Bandung	317	1.0443
	Weighed mean		1.0541

2) by measurements on local polygons

Bruxelles	1.0606
Canberra	1.0609
	1.0608

LCR 402 - 402 Z

Maker Calibration Factor K= 1.062

CONNECTIONS	M=Micrometer	g,dg	dg/dM	M(drift)
SOUTH PACIFIC				
Bruxelles -Noumea	4603.80	981117**		
76/06	2447.60	978833C		
	- 2156.20	- 2284	1.059	
Noumea - Suva	2448.40	978833C		+0.80
76/11	2212.10	978583C		
	- 236.30	- 250	1.058	
Suva - Papeete	2212.80	978583C		+0.70
77/05	2264.92	978639C		
	+ 52.12	+ 56	1.074	
ASIA				
Papeete - Teheran	2265.75	978639C		+0.83
77/11	2971.90	979388*		
	+ 706.15	+ 749	1.061	
Teheran - Tabriz	2971.00	979388*		-0.90
78/07	3333.01	979771C		
	+ 362.01	+ 383	1.060	
Tabriz - Bruxelles	3334.50	979771C		+1.49
79/06	4603.80	981117**		
	+ 1269.30	+ 1346	1.059	
Bruxelles - Wuhan	4603.80	981117**		0
79/10	2935.98	979349*		
	- 1667.82	- 1768	1.0600*	
Wuhan - Kunming	2935.80	979349*		-0.18
80/03	1992.45	978348*		
	- 943.35	- 1001	1.0611*	
Kunming - Mizusawa	1993.65	978348*		+1.20
81/06	3689.50	980148**		
	+ 1695.85	- 1800	1.0614*	
Mizusawa - Memambetsu	3688.90	980148**		-0.60
81/11	4080.10	980576*		
	+ 391.20	+ 428	1.094*	
Memambetsu - Kanoya	4078.00	980576*		-2.10
82/05	3027.60	979474*		
	-1050.40	- 1102	1.0491*	
Kanoya - Kathmandu	3026.40	979474*		-1.20
82/11	2301.10	978678C		
	- 725.30	- 796	1.097	
EUROPE				
Kathmandu - Bruxelles	2301.50	978678C		+0.40
83/12	4603.79	981117**		
	+ 2302.29	+ 2439	1.059	
Bruxelles - Kevo Z	4603.80	981117**		+0.01
84/04	5987.00	982588*		
	+ 1383.20	+ 1471	1.0635*	

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Kevo - Madrid 84/09	Z	5988.02 3518.70	982588* 979964**		+1.02
		- 2469.32	- 2624	1.0626*	

SOUTH AMERICA

Madrid - Arequipa 85/03	Z	3518.75 1421.80	979964** 977702*		
		- 2096.95	- 2262	1.0787*	
Arequipa - Chiclayo 85/10	Z	1421.50 1716.45	977702* 978051*		-0.30
		+ 284.95	+ 349	[1.225]	
Chiclayo - La Paz 86/04	Z	1716.25 1122.40	978051* 977428*		-0.20
		- 593.85	- 623	1.049*	
La Paz - Santa Cruz 86/11	Z	1121.60 1998.45	977428* 978349*		-0.80
		+ 876.85	+ 921	1.050*	
Santa Cruz - Quito 87/04	Z	1999.35 972.05	978349* 977270*		-0.10
		- 1027.30	- 1079	1.0503*	
Quito - Bogota 87/10	Z	972.90 1078.15	977270* 977373C		-0.85
		+ 105.25	+ 103	[0.979]	
Bogota - Cali 88/05	Z	1078.20 1505.60	977373C 977827C		+0.05
		+ 427.40	+ 454	1.062	
Cali - Caracas 88/12	Z	1505.40 1692.00	977827C 978025**		-0.20
		+ 186.60	+ 198	[1.061]	
Caracas - Ste Augustine 89/05	Z	1691.85 1828.00	978025** 978196C		-0.15
		+ 136.15	+ 145	[1.062]	
Ste Augustine - San José 89/11	Z	1827.70 1582.50	978196C 977932*		-0.30
		- 245.20	- 264	[1.077]	
San José - Mexico 90/03	Z	1581.90 1598.16	977932* 977949C		-0.60
		+ 16.26	+ 17	[1.046]	
Mexico - Bruxelles	Z	1599.50 4606.00	977949C 981117**		0.00
		+ 3006.50	+ 3168	1.054	

./...

Kevo - Kunming	5988.02	982588*	
84/09 81/06	1992.45	978348*	
	- 3995.57	- 4240	1.0611*

One absolute connection:

Bruxelles - Mizusawa	4603.80	981117.272**	
76/06 81/06	3689.20	980147.906**	
	- 914.60	- 969.366	1.05988**

Bruxelles -La Paz 76/06 86/04	- 3481.30	- 3689	1.0597*
Madrid - Quito 85/03 87/04	- 2546.30	- 2694	1.058*
Bruxelles - Quito 84/03 87/04	- 3630.90	- 3847	1.0595*
Bruxelles - Caracas	2911.79	3092.58	1.0621**
Madrid - Caracas	1826.75	1939	1.0614**

Eleven connections - Weighed mean (15.1 gal) 1.0622

LCR 906 Z

Maker Calibration Factor K= 1.018

CONNECTIONS		M=Micrometer	g,dg	dg/dM	ΔM(drift)
ARGENTINA					
Bruxelles - Migueletes	Z	4632.60	981117.272**		
88/09		3232.96	979689.069**		
		- 1399.64	1428.203	1.0204**	
Migueletes - Tacuarembo	Z	3232.97	979689.069**		+0.01
89/03		2964.20	979412.20**		
		- 268.77	- 276.869	1.0301**	
Tacuarembo - Zonda	Z	2965.25	979412**		+1.05
89/10		2699.90	979147C		
		- 265.35	- 265	1.000	
Zonda - Ushuaia	Z	2700.75	979147C		+0.85
90/04		4985.60	981471C		
		+ 2284.85	+ 2324	1.017	
Ushuaia - C.Rivadavia	Z	4986.50	981471C		-0.10
90/10		4201.00	980671C		
		- 785.50	- 800	1.018	
C.Rivadavia - Bruxelles		4202.60	980671C		
91/06		4650.30	981117.272**		
		+ 447.70	+ 446		
Ushuaia - Tacuarembo		2022.30	2076	1.027	
Two absolute connections				1.0252**	

RE-ANALYSIS OF BRAZILIAN TIDAL GRAVITY STATIONS WITH SENSITIVITY SMOOTHING METHOD AND COMPARISON OF TIDAL GRAVIMETRIC FACTORS.

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ABSTRACT

In this paper, we describe the re-analyses performed on the observations at twelve brazilian tidal gravity stations by an interactive procedure and we present a discussion about the results. We also present a comparison between the tidal factors and phase lags at Curitiba fundamental station related with the Brussels and Hannover calibrations.

1. INTRODUCTION

The brazilian section of the Trans World Tidal Gravity Profiles (TWTGP), presently with thirteen stations covering almost the whole territory of Brazil (Table 1, Fig.1) started in november 1983, in a cooperative project between the Royal Observatory of Belgium (ROB) and the Geodesy Postgraduate Course of the Federal University of Parana. The first step was the establishment of a fundamental station at Curitiba in an underground laboratory of the Geodesy Postgraduate School. The last station was established in the years 1987-88.

At the Curitiba fundamental station, the tidal gravimetric factors and phase lags for the main tidal waves were determined by means of observations in the same place with four instruments. A normalization of all instruments calibrated at the Brussels fundamental station and used in the South American section of the TWTGP was performed in this station.

The analyses of all brazilian tidal gravity stations were performed at the International Center for Earth Tides (ICET) with the standard computation procedures for Earth gravity tide analysis (DUCARME, B., 1975). This procedure follows a fully automatic sequence and is not completely satisfactory when there are anomalous conditions.

Recent observations at Curitiba fundamental station, performed with a Tidal LaCoste gravimeter operated by the Proudman Oceanographic Laboratory (Bidston Observatory - Liverpool), allowed a comparison of the tidal factors and phase lags related to the Brussels and Hannover calibrations.

2. ADOPTED PROCEDURE

To revise 12 brazilian tidal gravity stations where different instruments with different behaviours have been used with different local conditions for maintenance, we followed a basic sequence of sensitivity smoothing before the harmonic analysis (DUCARME, B., 1979) and procedures to take into account the different instrumental behaviours and all available informations. The sequence is :

a) Application of MT332 ICET computation program based on Nakai method to compare observed and theoretical Earth tides (NAKAI, S., 1977). It takes advantage of the gravimetric factors previously obtained in the standard analysis. The output helps to detect discordant data jumps or drifts in the sensitivity. Anomalous 48h data sequence are detected by phase discrepancies or/and big RMS errors of the adjusted amplitudes. From this analysis and also from the data sequence interruptions, we took decision to keep or to eliminate 48h data sequences after revision of the original data, and/or to divide the smoothed series in sections for subsequent analyses.

b) Application of MR41 ICET computation for the smoothing of time series by the Vondrak procedure (PAQUET, P. & HONOREZ. M., 1972). The output shows the standard deviation for smoothed sensitivities by three different smoothing factors. It is possible to select the most suitable factor and again to reject anomalous 48h data sequences.

c) Application of MT42 ICET computation program for comparison of smoothed apparent sensitivity obtained by MT332 with real calibration data. From the comparison between observed (d) and adjusted displacements of calibration (d') we can eliminate doubtful calibrations (by comparison with their adjusted values) and find the amplitude adjustement factors K to compute a smoothed calibration factor C' by :

$$C' = K\,C \qquad (1)$$

with

$$K = (\Sigma\, d'/d)/n \qquad (2)$$

where n is the number of accepted calibrations and C is the initial calibration factor.

d) Application of MT41b ICET computation program to compute an improved and smoothed calibration table, from the partial or mean amplitude adjustement factor and the MT332 smoothed series.

e) Application of MT61 ICET computation program (VENEDIKOV filters) on Earth tides data multiplied by smoothed calibration factors interpolated in the improved table with elimination of the bad 48h data sequences detected in the steps a) and b).

f) Application of MT71 ICET computation program on VENEDIKOV filters to obtain the final results of tidal analysis. The results of these analyses are presented in the Tables 8 to 18.

g) Application of MT711 ICET computation program for subtraction of loading effects, based on Schwiderski maps (SCHWIDERSKI, E.W., 1980) for 8 oceanic waves -Diurnals : Q1, O1, P1, K1; -Semi-diurnals : N2, M2, S2, K2. The results of these computations are in the Tables 19 to 29.

For each station we performed different analyses with : 1) addition or suppression of data; division of the smoothed series in sections; ii) change in the smoothing factor; iii) re-normalisation of the instrument and change of phase lag to take into account other determined values for the same instrument in another place or re-computation of new values taking into account other observations with another instrument in the same place.

The Earth gravity tidal final residue vector is defined (MELCHIOR, P., et alii, 1989) for each component wave as :

$$\bar{X}(X,\chi) = \bar{B}(B,\beta) - \bar{L}(L,\lambda) \qquad (3)$$

where : $\bar{B}$ - residue vector (MELCHIOR, P. & DE BECKER, M., 1983) given by the difference between the observed tidal vector and the calculated tidal vector for an elastic Earth model with liquid core;

$\bar{L}$ - load vector which contains the periodic oceanic loading, the periodic attraction effects and the periodic change of potential (MELCHIOR, P., 1983). (figures 2, 3)

In this work the quality factors are those defined by CHUECA, R. et alii (1984) as :

$$Q1 = 10R(1 + P) / \sqrt{e_1 . e_2} \qquad (4)$$

and

$$Q2 = R / \sqrt{e(O1) . e(M2)} \qquad (5)$$

where : R - station's efficiency (N° of readings / 24 x N° of days)

e_1 - standard deviation in the diurnal band

e_2 - standard deviation in the semi-diurnal band

e(01) - mean square error on 01 observed amplitude

e(M2) - mean square error on M2 observed amplitude

p - weight to diurnal waves separation (p=0 no separation of P1 S1 K1; p=1 with satisfactory (*) separation of P1 from K1; p=2 with satisfactory separation of PSI1).

3. RESULTS AND REMARKS

For the normalization of all instruments in the standard analysis and re-analysis as well, the calibration factors were adjusted to obtain at the Bruxelles fundamental station (MELCHIOR, P. et alii., 1989) as tidal gravimetric factor for 01 wave :

$$\delta(01) = 1.161 \quad (6)$$

and instrumental phase lags at Bruxelles fundamental station (DUCARME, B., 1983) :

$$\alpha(01) = -0.2° \quad \text{and } \alpha(M2) = 2.8° \quad (7)$$

The normalization factors and phase corrections for all re-analysed brazilian tidal gravity stations related to the Brussels system are given in the re-analysis outputs (Tables 8 to 18). Based on this system, the main tidal gravimetric factors δ M_2)** was adjusted and the instrumental phases lags α were determined at Curitiba fundamental station using the four instruments calibrated at Brussels fundamental station (MELCHIOR, P. et alii., 1989), giving

$$\delta(M2) = 1.1746 \quad (8)$$

$$\alpha(01) = -1.24° \pm 0.13° \quad \text{and} \quad \alpha(M2) = 1.41° \pm 0.05° \quad (9)$$

and, as a mean value

$$\delta(0_1 = 1.1835\ (**) \pm 0.0049$$

(*) It is considered as satisfactory when the length of the records is larger than 6 months and when β(P1) is not different from β(K1) by more than 10°, etc...

(**) The O_1 wave amplitude is only 28 μgal at Curitiba while the M_2 wave amplitude reaches 72 μgal. This is why we decided to use M_2 wave for the calibrations. At Bruxelles both waves have the same amplitude : 35μgal.

All stations of the brazilian tidal gravity profile are thus consistent with the TWTGP and with the MOLODENSKY model I (elastic and oceanless Earth) as well.

The δ factors in the TWTGP are reduced by a correction proportional to the square of the angular speed of the wave to take into account the inertial effects. These corrections are given for the waves with angular speed $_i$ (DUCARME, B., 1975) by:

$$\tau = 0.0041\, \omega_i^2 / \omega^2(S_2) \qquad (10)$$

where (S2) is the angular speed of the tidal wave S2. These corrections at Curitiba fundamental station are respectively :

$$\tau\,(01) = 0.0009 \qquad \text{and } \tau\,(M2) = 0.0038 \qquad (11)$$

Using these values we obtain at the Curitiba fundamental station, the tidal factors without inertial corrections :

$$\delta\,(01) = \begin{array}{c}1.1844\\ \pm\, 0.0049\end{array} \qquad \text{and } \delta\,(M2) = 1.1784 \qquad (12)$$

Recent measurements carried out at this station with the LC ET10 instrument gave (R.J. EDGE, 1990 *) :

$$\delta\,(01) = \begin{array}{c}1.1713\\ \pm\, 0.0020\end{array} \qquad \text{and} \qquad \delta\,(M2) = \begin{array}{c}1.1692\\ \pm\, 0.0004\end{array} \qquad (13)$$

(without the inertial corrections) which are consistent with the Hannover calibration baseline and

$$\alpha\,(01) = \begin{array}{c}-0.98^\circ\\ \pm\, 0.09^\circ\end{array} \qquad \text{and} \qquad \alpha\,(M2) = \begin{array}{c}1.45^\circ\\ \pm\, 0.02^\circ\end{array} \qquad (14)$$

to be compared with (9).

The results of the re-analysis at 12 brazilian tidal gravity stations are given in the Table 2 and comparative Tables 4 to 6. The results of the standard analysis at the same stations (MELCHIOR, P. et alii, 1989) are given in the Table 3 and comparative Tables 4 to 6.

The Table 7 gives for each station respectively : i) the ICET station code number; ii) the instrument (LaCoste & Romberg models D and G - LC, LaCoste & Romberg with feedback system -LCZ and Geodynamics - GEO) and their normalization factors; iii) the considered re-analysis interval; iv) the number of elapsed days in the considered interval; v) the number of days lost in the considered interval related to interruptions in the records or elimination with basis on the output of MT332 and MT41 ICET computation programs;

(*) Edge considers the calibration of ET 15 accurate to 0.2% "The rms errors being only the internal ones".

vi) the number of calibrations performed in the considered interval, the mean number of calibrations per week and the number of satisfactory calibrations in comparison with the smoothed series; vii) the number of drift corrections in the considered interval and their mean value per week; viii) the standard and smoothed calibration factors; ix) the mean calibration displacements values and their dispersion (related with the stability in the sensitivity); x) the number of sections in which we divided the smoothed series for the re-analysis; xi) the adopted smoothing factor to compute the smoothed calibration table. This table shows that :

a) The mean number of the days of interruptions in the readings for all stations is 44 days, due mainly to minor problems of maintenance or interruptions in power supply. On the other hand, we eliminated a mean number of 10 days in the re-analyses due to bad records. This emphasizes local difficulties for maintenance and the satisfactory instrumental behaviour in normal operation.

b) If one considers that it is sufficient to perform one calibration per week for LaCoste & Romberg instruments and one to two, for Geodynamics instruments, then for all brazilian stations the mean values of 0.95 and 1.38 respectively are satisfactory. In this sense, only the Manaus station (7315) is far from the mean;

c) The numbers of drift corrections per week at station 7306, Santa Maria (LC D32), at station 7308, Viçosa (LC G3) and at station 7312 Presidente Prudente (LCZ G487) were respectively 2.68, 2.55 and 3.80 which are abnormally high.

d) The fluctuations of the sensitivities of these three instruments at these same stations have been respectively 12%, 25% and 3%. Viçosa station is thus obviously to be rejected from the ICET Data Bank. Indeed, after its transformation into zero method the LC G3 variations of sensitivity, when installed at station 7315 Manaus were only 1.6% instead of the 25% at Viçosa.

The results of analysis and re-analysis in the Cuiaba station (7309) are not immediately comparable because we divided the re-analysis into two parts (84-11-25 to 85-02-14 and 85-06-01 to 85-07-11) as there is an apparent change in both normalisation factor and phase lag after a long interruption and a change in sensitivity between these two parts.

The re-analysis of the Teresina station (7813) was not possible by the adopted procedures, because there is a great instability in the reported voltages of calibration producing spurious instabilities in the sensitivity. In its re-analysis we took advantage of the reported reference voltage and the corrected amplitude adjustment factor obtained at the Vassouras station (7314) for the same instrument (GEO 783). As this procedure was successfull, it appears that, in the Teresina station, this instability in voltage is only related with its measured values (voltmeter defect). The G783 gravimeter sensitivity has always been very stable.

4. CONCLUSIONS

The Tables 2 to 6 show that the re-analysis procedures give systematically smaller standard deviations in all bands, better efficiencies, better quality factors while the residues are in better agreement with loading effects.

RATTON, E., 1986 considered the results for the stations Santa Maria (LC D32) and Viçosa (LC G3) as doubtful and the Campo Grande station (7307) as perturbed in the diurnal band. In the re-analysis we found smaller residues for the main waves at Santa Maria station (7306), where in the re-analysis there is only a large residue for the K1 wave after loading corrections. Viçosa station (7308) results with the LC 3 remains however very doubtful because of instrumental problems as already mentioned in section 3, but the re-measurement with the instrument LC G8 was improved in the re-analysis. At Campo Grande station diurnal perturbations are obviously present.

At Belém station (7316), the large $X \sin\chi$ residue for the M2 wave is due to a local lack of precision of the Schwiderski maps for coastal loading effects computations. It can not be the case for the Manaus station (7315) which is 1250 km far from the ocean. At Manaus we found a good stability of sensitivity but a too small number of calibrations. In its re-analysis we used some reported drift corrections in substitution of absent calibrations. The results of this station are doubtful due to maintenance problems.
The absence of reports on the instrumental conditions (mainly on the level changes) and meteorological data, emphasize the difficulties for a conclusive analysis of instrumental behaviour at some stations, but it is remarkable that the mean values of the residues $X \cos\chi$ and $X \sin\chi$ for the waves O1 and M2 are close to zero (see Table 9). This shows that good results have been obtained in Brazil for the measurements and for the loading corrections calculated on the basis of the Schwiderski maps.

The tables 2 to 7, show that the quality factors are only an initial indicator of the trustfulness of results at one station, because there are events (e.g. station's efficiency defined in the section 2) that reduce the quality factors in a good stations (with little RMS, good maintenance, and good instrumental conditions).

We recommend the adoption for the TWTGP the re-analysed results at the stations : 7306 (LC D32), 7307 (LCZ G3), 7309 (GEO 783-1st part), 7310 (GEO 783), 7311 (LCZ G8), 7312 (LCZ G487), 7313 (GEO 783), 7314 (GEO 783), 7316 (LCZ G3), and 7317 (LCZ G8).

DEHANT, V. & DUCARME, B., 1987 pointed out a global disagreement slightly less than one per cent between the tidal factors computed with the WAHR-DEHANT model (elliptical, rotating, inelastic and oceanless Earth) and those obtained from observed main tidal waves.
Other authors pointed out from observations with independently calibrated instruments, that the tidal gravimetric factors at Brussels fundamental station should be decreased by about one per cent (DUCARME, B. & VAN RUYMBEKE, M., 1989; BAKER, T.F. et alii, 1989). At the Curitiba fundamental station, the values observed with the LCR ET10 instrument are in agreement with the WAHR-DEHANT model. Thus, ratios for the tidal amplitude factors, without inertial corrections, are respectively :

for O1 : δ(Brussels calibration)/δ(Hannover calibration) = 1.011

for M2 : δ(Brussels calibration)/δ(Hannover calibration) = 1.008

As the internal precision in both calibration systems is 0.2%, we also recommend the correction of minus one per cent in the gravity factors at Brussels fundamental station and for all observed tidal factors for the TWTGP.
For what concerns however the phase lags determined on the basis of the Bruxelles calibration (eqn.9) or obtained by Edge with the Tidal LaCoste ET 10 instrument (eqn.14), the agreement is perfect for M_2 (0.04° difference only) and good for O_1 (0.26° difference).

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The installations of the gravimeters at all the stations were successfully performed by C. Poitevin and E. Ratton. At Curitiba some instruments were installed also by B. Ducarme and M. Van Ruymbeke. J. Bittencourt participated in the installation of the stations Santa Maria and Presidente Prudente. Moreover M. Van Ruymbeke installed the feedback electronics in the LaCoste Romberg gravimeters G3, G8, G487 and D32 during his stay in Curitiba. We wish to thank our colleagues for their efficient work.

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TABLE 1 - Brazilian tidal gravity stations.

STATION/NUMBER	LAT.	LONG.	ALT.(m)	PF.(m)	D.SEA(km)
CURITIBA - 7305	25 27S	49 14W	913	3	80
SANTA MARIA - 7306	29 40S	53 49W	700	2	330
CAMPO GRANDE- 7307	20 27S	54 36W	450	0	1000
VIÇOSA - 7308	20 45S	42 52W	650	0	400
CUIABA - 7309	15 36S	56 07W	154	0	1882
GOIANIA - 7310	16 37S	49 15W	764	0	875
CAICO - 7311	06 31S	37 08W	190	0	200
P.PRUDENTE - 7312	22 07S	51 24W	430	0	500
TERESINA - 7313	05 03S	42 48W	70	0	350
VASSOURAS - 7314	22 24S	43 39W	468	0	80
MANAUS - 7315	03 10S	59 50W	40	0	1250
BELEM - 7316	01 30S	48 30W	4	0	150
SALVADOR - 7317	12 58S	38 29W	15	0	1

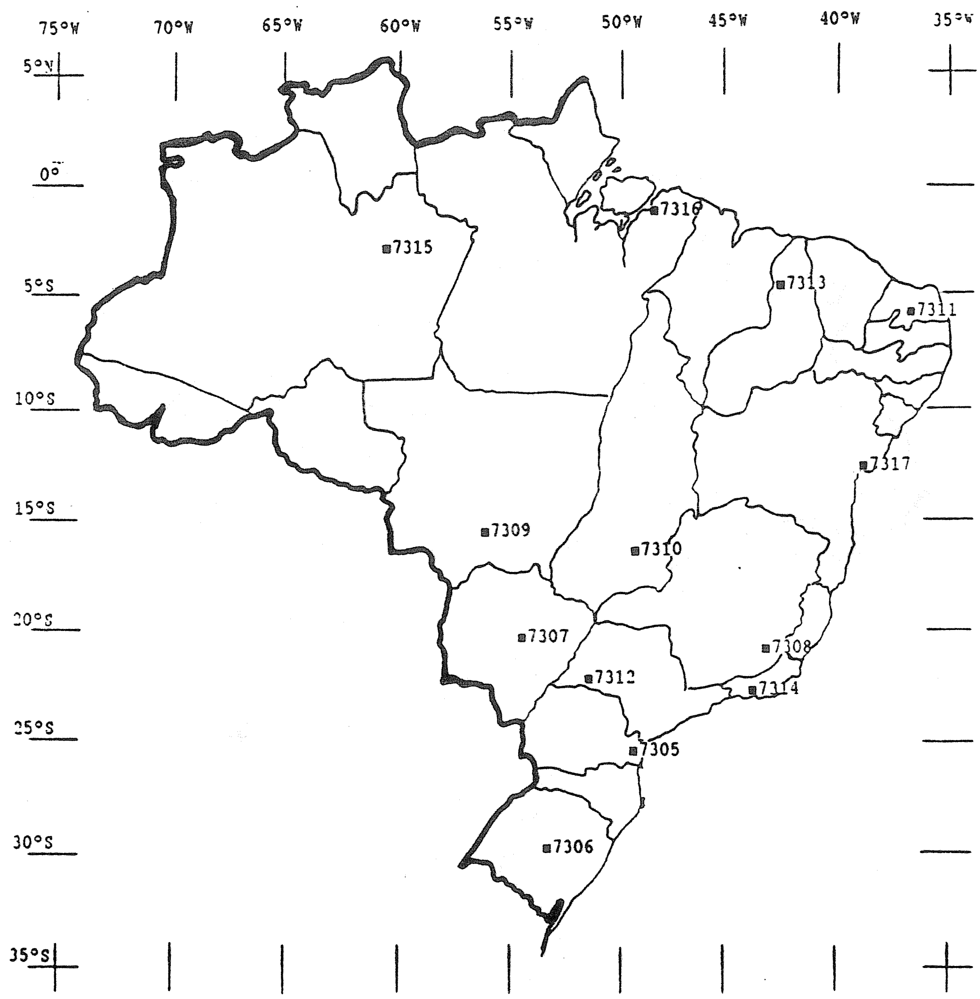

FIGURE 1 - Brazilian tidal gravity stations

FIGURE 2 - Loading effects for the O1 wave (in µGal) peak to peak

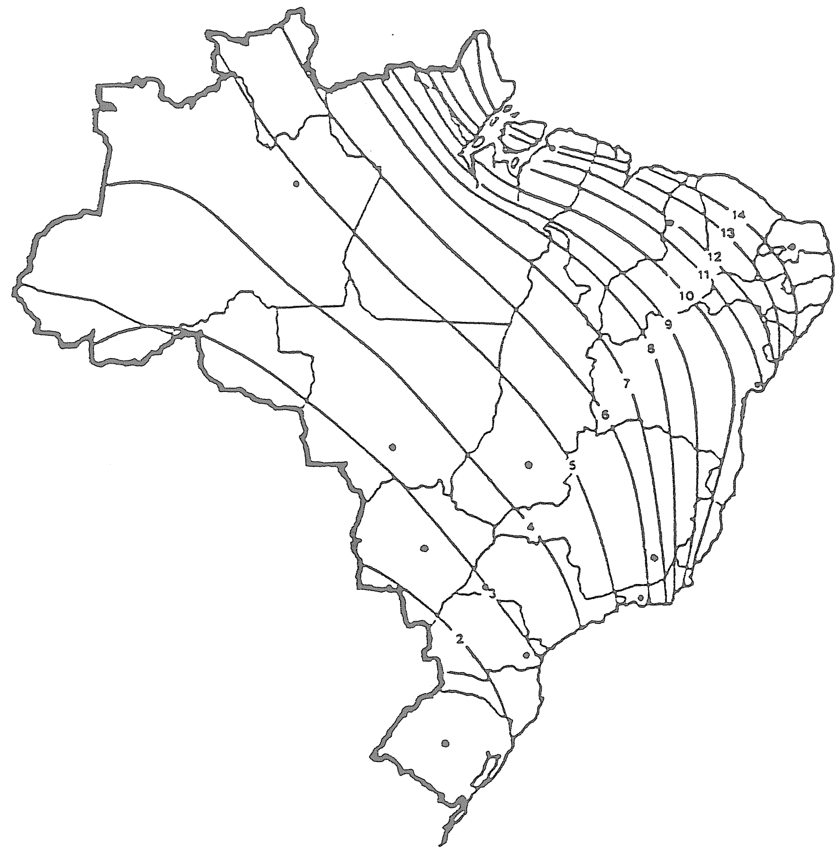

FIGURE 3 - Loading effects for the M2 wave (in µGal) peak to peak

TABLE 2 - Re-analysis of brazilian gravity tidal stations.

STATION	GRAV.		INT.	R	STD1	STD2	STD3	Q 1	Q 2
7306	LC	D32	175.0	.66	6.96	5.12	2.91	2.2	3.5
7307	LCZ	G3	119.0	.61	11.77	6.39	2.91	0.7	1.8
7308	LC	G3	185.5	.79	7.42	4.92	2.58	2.6	4.8
7308	LCZ	G8	58.5	.58	5.30	1.77	0.84	1.9	3.0
7308	LC	G8	136.5	.91	4.37	2.28	1.42	2.9	10.5
*7309	GEO	783	82.5	.82	5.24	3.44	1.11	1.9	5.1
*7309	GEO	783	42.0	1.00	6.95	3.06	1.72	2.2	4.3
7310	GEO	783	199.0	.75	3.32	2.42	0.88	5.3	10.0
7311	LCZ	G8	230.5	.84	3.68	2.41	0.96	5.6	12.2
7312	LCZ	G487	190.0	.89	6.03	2.57	1.70	4.5	9.6
7313	GEO	783	306.0	.70	2.74	1.59	0.93	6.7	15.9
7314	GEO	783	348.0	.55	3.66	2.80	1.26	3.4	7.4
7315	LCZ	G3	233.5	.62	7.70	2.99	1.25	2.6	4.8
7316	GEO	783	198.5	.84	3.06	5.80	1.27	4.0	8.3
7317	LCZ	G8	287.0	.50	4.11	2.37	0.94	3.2	5.6

TABLE 3 - Brazilian gravity tidal data from standard analysis.

STATION	GRAV.		INT.	R	STD1	STD2	STD3	Q 1	Q 2
7306	LC	D32	175.0	.63	6.82	4.70	2.82	2.2	3.3
7307	LCZ	G3	117.0	.65	13.76	7.49	2.73	0.6	1.7
7308	LC	G3	166.5	.68	9.04	4.56	2.73	2.1	3.2
7308	LCZ	G8	58.5	.58	5.17	4.44	0.86	1.2	1.9
7308	LC	G8	136.5	.94	5.18	4.04	1.42	2.0	7.6
7309	GEO	783	225.5	.41	8.86	3.92	1.36	1.4	1.7
7310	GEO	783	199.5	.79	3.70	3.11	0.89	4.7	9.1
7311	LCZ	G8	230.5	.89	4.56	4.35	0.98	4.0	8.9
7312	LCZ	G487	190.0	.89	6.75	3.06	1.82	3.9	8.2
7313	GEO	783	327.0	.72	2.82	3.44	0.91	4.6	11.6
7314	GEO	783	348.0	.52	4.28	4.04	1.30	2.5	5.1
7315	LCZ	G3	233.5	.69	8.26	3.75	1.30	2.5	4.9
7316	GEO	783	198.5	.86	3.06	6.05	1.27	4.0	8.4
7317	LCZ	G8	285.0	.50	2.47	4.65	0.68	2.9	5.0

Remarks on tables 2 and 3 :

* - Analysis in two parts (84-11-26 to 85-2-14 and 85-6-01 to 85-7-11)

STD1, STD2, STD3 - Standard deviation in μGal respectively of diurnal, semi-diurnal and ter-diurnal waves.

Q1, Q2 - Quality factors defined in the section 2.

R - Station's efficiency defined in the section 2.

TABLE 4 - Final residues $\bar{X}$ (X, Chi) of standard analysis and re-analysis at brazilian tidal gravity stations.

STATION	WAVE	DATA BANK ICET X	DATA BANK ICET Chi	RE-ANALYSIS X	RE-ANALYSIS Chi
7306	O1	0.83	35.3	0.92	37.4
	M2	1.55	-169.8	0.98	-166.8
7307	O1	1.06	13.1	0.87	40.4
	M2	0.36	-153.3	0.16	-120.7
7308 LC G3	O1	0.31	122.9	0.42	52.7
	M2	0.87	-154.4	1.28	-158.1
7308 LC G8	O1	0.62	23.0	0.57	35.8
	M2	0.87	-154.3	1.27	-158.4
7309 (1st.p)	O1	0.67	64.8	0.20	120.1
	M2	0.82	137.6	0.35	51.3
7309 (2nd.p)	O1	0.67	64.8	0.29	101.3
	M2	0.82	137.6	0.50	116.6
7310	O1	0.15	31.6	0.20	12.9
	M2	0.66	131.4	0.81	147.7
7311	O1	0.11	-170.8	0.08	134.4
	M2	0.61	133.0	0.58	129.9
7312	O1	0.33	130.7	0.23	86.8
	M2	0.27	-93.0	0.28	-119.6
7313	O1	0.22	144.0	0.18	143.1
	M2	1.14	3.1	1.16	6.3
7314	O1	0.33	104.2	0.36	98.5
	M2	0.60	0.2	0.53	-6.5
7315	O1	0.39	89.4	0.34	100.2
	M2	1.30	-89.6	1.36	-110.2
7316	O1	0.30	-98.5	0.29	-97.0
	M2	2.22	125.9	2.19	126.9
7317	O1	0.33	34.4	0.20	38.2
	M2	1.19	151.1	0.76	137.9

TABLE 5 - Final residues components of standard analysis and re-analysis at brazilian tidal gravity stations.

STATION	WAVE	DATA BANK ICET		RE-ANALYSIS	
		XcosChi	XsinChi	XcosChi	XsinChi
7306	O1	0.67	0.48	0.73	0.56
	M2	-1.53	-0.27	-0.95	-0.22
7307	O1	1.03	0.24	0.66	0.56
	M2	-0.32	-0.16	-0.08	-0.14
7308 LC G3	O1	-0.17	0.26	0.25	0.33
	M2	-0.78	-0.37	-1.19	-0.48
7308 LC G8	O1	0.57	0.24	0.46	0.33
	M2	-0.78	-0.38	-1.18	-0.46
7309 (1st.p)	O1	0.28	0.60	-0.10	0.17
	M2	-0.63	0.55	0.21	0.27
7309 (2nd.p)	O1	0.28	0.60	-0.06	0.28
	M2	-0.63	0.55	-0.22	0.45
7310	O1	0.13	0.08	0.19	0.04
	M2	-0.44	0.49	-0.68	0.43
7311	O1	-0.11	-0.02	-0.06	0.06
	M2	-0.42	0.45	-0.37	0.44
7312	O1	-0.22	0.25	0.01	0.23
	M2	-0.01	-0.27	-0.14	-0.24
7313	O1	-0.14	0.17	-0.14	0.11
	M2	1.14	0.06	1.15	0.13
7314	O1	-0.08	0.32	-0.05	0.35
	M2	0.60	0.00	0.53	-0.06
7315	O1	0.00	0.39	-0.06	0.33
	M2	0.01	-1.30	-0.47	-1.28
7316	O1	-0.05	-0.30	-0.04	-0.29
	M2	-1.30	1.80	-1.31	1.75
7317	O1	0.27	0.19	0.16	0.12
	M2	-1.04	0.57	-0.56	0.51

TABLE 6 - Mean values for twelve brazilian gravity tidal stations in comparable (*) analysis and re-analysis.

MEAN VALUES TO	DATA BANK ICET	RE-ANALYSIS
TIME INT.(DAYS)	222	209
EFFICIENCY	.71	.72
STD DIURNAL WAVES	5.88	5.22
STD SEMI-DIUR. WAVES	4.38	3.35
STD TER-DIUR. WAVES	1.46	1.46
QUAL. FACTOR Q1	2.94	3.58
QUAL. FACTOR Q2	6.29	7.89
X cos(Chi) - O1	0.20	0.15
X cos(Chi) - M2	-0.39	-0.36
X sin(Chi) - O1	0.22	0.21
X sin(Chi) - M2	0.13	0.09

(*) - In this comparison we considered:

a) The gravity tidal stations - 7306, 7307, 7308, 7309, 7310, 7311, 7312, 7313, 7314, 7315, 7316 and 7317;

b) The analysis and re-analysis at Viçosa station (7308) only with the LC G8 instrument;

c) The analysis at Cuiaba station (7309) and the first part of re-analysis.

TABLE 7 - SOME DATA OF RE-ANALYSIS AT BRAZILIAN TIDAL GRAVITY STATIONS

STATION NUMBER	INSTRUM./ NORM. FACT.	CONSIDERED INTERVAL	NUMBER OF DAYS	DAYS OUT OF ANALYSIS BY INTERR.	ELIMIN.	NUMBER OF CALIBRAT. MADE	/WEEK	SATISF.	DRIFT CORRECTIONS MADE	/WEEK	CALIBRATION FACTOR C	C'	DISPLACEMENTS OF CALIBR. MEAN	DISP.(%)	SMOOTHING SECTIONS	SMOOTHING FACTOR
7306	LC D32 .92635	83-11-03 84-04-24	175	50	10	12	0.67	11	48	2.68	1.221	1.074	5.100	11.96	5	.0001
7307	LCZ G3 .98846	85-03-14 85-07-09	119	32	14	09	0.72	06	07	0.56	1.041	1.012	7.615	5.04	1	.0001
7308	LC G3 .93818	83-11-03 84-05-04	185	09	30	26	1.03	05	64	2.55	1.041	1.050	7.298	25.04	3	.0001
7308	LCZ G8 1.00247	86-08-08 86-10-03	58	20	04	13	1.57	08	05	0.60	1.000	0.988	7.115	3.02	1	.0001
7308	LC G8 .95933	86-10-09 87-02-20	136	08	04	21	1.14	12	11	0.57	1.000	1.058	6.291	17.53	2	.001
7309	GEO 783 .95099	84-11-26 25-02-14	83	07	08	14	1.29	14	04	0.37	1.010	1.056	5.497	1.54	1	.0001
7309	GEO 783 .95099	85-06-01 85-07-11	42	00	00	09	1.50	09	04	0.67	1.010	1.037	5.261	4.43	1	.001
7310	GEO 783 .95099	84-05-04 84-11-17	199	34	16	55	2.33	37	04	0.17	1.010	1.099	5.565	6.03	2	.001
7311	LCZ G8 1.00247	84-12-11 85-07-29	231	27	10	35	1.20	32	45	1.54	1.000	.9964	7.191	3.35	2	.0001
7312	LCZ G487 .99641	86-11-21 87-05-28	190	13	08	30	1.19	29	96	3.80	1.025	1.003	4.441	3.30	1	.0001
7313	GEO 783 .95099	86-08-17 87-06-19	306	84	08	33	1.04	10	09	0.28	1.010	1.104	4.910	15.41	2	.001
7314	GEO 783 .95099	87-06-29 88-06-09	348	135	22	42	1.38	15	07	0.23	1.010	1.104	5.214	23.36	3	.001
7315	LCZ G3 .98846	85-07-19 86-03-08	234	81	08	04	0.18	02	33	0.32	1.041	1.028	7.595	1.55	1	.001
7316	GEO 783 .95099	85-07-26 86-02-07	199	28	04	18	0.74	16	02	0.29	1.010	1.104	5.553	1.31	1	.0001
7317	LCZ G8 1.00247	85-08-06 86-05-18	287	134	10	23	1.05	21	13	0.32	1.000	1.003	7.384	2.78	2	.001

Table 8

TRANS WORLD PROFILE SOUTH AMERICA STATION SANTA MARIA

STATION 7306 SANTA MARIA RIO GRANDE DO SUL COMPOSANTE VERTICALE BRESIL
29 40 17S 53 49 22W H 700M P 2M D 330KM
DEPOTS SEDIMENTAIRES SUR BASALTE
DEPT. DE INGENIERIA RURAL-UNIV. FED. DE SANTA MARIA PROF. E.LEVISKI
CENTRO POLITECNICO-GEODESIA-U.F.PR. PROF. C.GEMAEL
GRAVIMETRE LA COSTE ROMBERG D 32 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
CALIBRATION CURITIBA - STATION FONDAMENTALE
INSTALLATION B.DUCARME,J.BITTENCOURT
MAINTENANCE E.LEVISKI,LUIZ A.AITA

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 1/31

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .92635
PHASE LAG O1 2.249 M2 1.381 O1/M2 1.629
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.01747 /MODEL 2/

G 32 8311 3/8311 5 8311 9/831121 831125/8312 1 8312 6/831210 831213/831223
G 32 84 112/84 2 5 84 210/84 212 84 3 9/84 4 2 84 4 6/84 416 84 422/84 424

TIME INTERVAL 175.0 DAYS 2784 READINGS 10 BLOKS EFFICIENCY .66

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	5.89	.21	1.1526	.0418	-2.259	2.055	.24	80.3
143.-145.	16	O1	30.89	.21	1.1567	.0080	-1.401	.395	.76	84.1
152.-155.	15	NO1	2.68	.18	1.2769	.0834	-3.221	3.752	.29	148.3
161.-163.	10	P1	14.06	.21	1.1316	.0172	-2.914	.870	.77	67.8
164.-168.	23	S1K1	41.99	.21	1.1181	.0057	-1.529	.293	1.35	56.3
175.-177.	14	J1	2.48	.21	1.1818	.1005	.661	4.868	.05	-146.3
184.-186.	11	OO1	1.12	.17	.9734	.1458	-1.439	8.585	.22	7.4
233.-23X.	20	2N2	2.31	.13	1.3325	.0778	-.674	3.387	.30	-5.2
243.-248.	24	N2	12.75	.17	1.1746	.0156	-.094	.776	.16	-7.6
252.-258.	26	M2	65.40	.16	1.1541	.0029	.255	.145	.45	139.4
265.-265.	9	L2	1.87	.13	1.1644	.0784	1.466	3.918	.05	82.5
267.-273.	9	S2	30.41	.15	1.1534	.0058	.153	.289	.19	155.2
274.-277.	12	K2	8.47	.14	1.1811	.0194	-.764	.955	.19	-36.9
327.-375.	17	M3	1.25	.09	1.2944	.0920	3.409	4.115	.23	18.9

STANDARD DEVIATION D 6.96 SD 5.12 TD 2.91 MICROGAL

QUALITY FACTORS : Q1= 2.2 Q2= 3.5
O1/K1 1.0345 1-O1/1-K1 1.3267 M2/O1 .9978
CENTRAL EPOCH TJJ= 2445728.0

Table 9

TRANS WORLD PROFILE   SOUTH AMERICA   STATION CAMPO GRANDE

STATION 7307 CAMPO GRANDE   MATTO GROSSO DO SUL   COMPOSANTE VERTICALE BRESIL
20 27 49S   54 36 55W   H 450M   P   0M   D 1000KM
FORMATION SABLEUSE(ARENITO CAMA) 40M SUR BASALTE
DPT. DE HIDRAULICA E TRANSPORTE - UNIV. FED. DE MATTO GROSSO DO SUL
CENTRO POLITECNICO-GEODESIA-U.F.PR.   PROF. C.GEMAEL
GRAVIMETRE LA COSTE ROMBERG 3 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
ASSERVISSEMENT ELECTRONIQUE M. VAN RUYMBEKE
AJUSTEMENT DE LINEARITE PAR METHODE SATO-HARRISON
CALIBRATION   CURITIBA   STATION FONDAMENTALE
INSTALLATION   C.POITEVIN,E.RATTON
MAINTENANCE   AGRIMAL ARAUJO

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER   INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81   PROCESSED ON 90/ 2/12

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR   .98846

G 3 85 314/85 326 85 4 1/85 4 7 85 412/85 412 85 415/85 423 85 514/85 520
G 3 85 524/85 6 3 85 614/85 616 85 619/85 619 85 625/85 627 85 7 1/85 7 5
G 3 85 7 9/85 7 9

TIME INTERVAL   119.0 DAYS   1728 READINGS   11 BLOKS   EFFICIENCY .61

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-139.	30	Q1	5.21	.42	1.3391	.1072	7.710	4.566	.96	-133.0
143.-149.	26	O1	23.18	.43	1.1405	.0213	-1.574	1.068	.75	58.5
161.-168.	33	P1S1K1	29.77	.43	1.0414	.0149	-3.538	.806	3.35	33.2
243.-248.	24	N2	14.24	.26	1.1290	.0205	1.248	1.052	.50	141.9
252.-258.	26	M2	77.03	.27	1.1695	.0041	.724	.203	1.15	57.8
267.-277.	21	S2K2	37.57	.25	1.2262	.0081	-.439	.375	2.04	-8.1
327.-375.	17	M3	1.53	.12	1.2655	.0950	10.268	4.307	.35	51.7

STANDARD DEVIATION   D   11.77   SD   6.39   TD   2.91 MICROGAL

QUALITY FACTORS : Q1=   .7 Q2=   1.8
O1/K1 1.0952   1-O1/1-K1 3.3930   M2/O1 1.0254
CENTRAL EPOCH TJJ= 2446197.0

Table 10

TRANS WORLD PROFILE SOUTH AMERICA STATION CUIABA

STATION 7309 CUIABA MATTO GROSSO N COMPOSANTE VERTICALE BRESIL
15 36 33 S 56 07 34 W H 154 M P 0M D 1882KM
PRECAMBRIAN,PHYLLITES AND QUARTZITES,LOW GRADE METAMORPHIC ROCK
UNIVERSIDADE FEDERAL DE MATTO GROSSO - DEPARTAMENTO DE GEOLOGIA
GRAVIMETRE GEODYNAMICS 783 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
CALIBRATION BRUXELLES - FUNDAMENTAL STATION/NC50.4V/
INSTALLATION C.POITEVIN,E.RATTON
MAINTENANCE N.NAVEEN CHANDRA,K.J.ALBRECHT

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COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 2/19

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .95099
PHASE LAG O1 .337 M2 .647 O1/M2 .521
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.00282 /MODEL 2/

G783 841126/841210 841214/841222 85 1 3/85 210 85 214/85 214

TIME INTERVAL 82.5 DAYS 1632 READINGS 4 BLOKS EFFICIENCY .82

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-139.	30	Q1	3.56	.22	1.1558	.0723	3.670	3.577	.23	-85.3
143.-149.	26	O1	18.88	.19	1.1745	.0116	-.621	.564	.32	139.9
161.-168.	33	P1S1K1	26.11	.16	1.1544	.0070	1.665	.343	.84	-115.9
243.-248.	24	N2	15.64	.17	1.1742	.0125	1.740	.606	.51	69.2
252.-258.	26	M2	81.81	.14	1.1757	.0020	1.114	.098	1.92	56.1
267.-277.	21	S2K2	37.87	.16	1.1698	.0048	1.251	.235	.88	69.7
327.-375.	17	M3	1.42	.05	1.0777	.0345	2.508	1.821	.06	78.8

STANDARD DEVIATION D 5.24 SD 3.44 TD 1.11 MICROGAL

QUALITY FACTORS : Q1= 1.9 Q2= 5.1
O1/K1 1.0174 1-O1/1-K1 1.1300 M2/O1 1.0010
CENTRAL EPOCH TJJ= 2446071.0

Table 11

TRANS WORLD PROFILE SOUTH AMERICA STATION GOIANIA

STATION 7310 GOIANIA GOIAS COMPOSANTE VERTICALE BRESIL
16 37 13 S 49 15 19W H 764M P 0M D 875KM
GNAISSES DO COMPLEXO BASAL GOIANO(PRECAMBRIANO),LATOSSOLO VERMELHO-AMARELADO
UNIVERSIDADE FEDERAL DE GOIAS - INSTITUTO DE QUIMICA E GEOCIENCIAS
CENTRO POLITECNICO-GEODESIA-U.F.PR. PROF. C.GEMAEL
GRAVIMETRE GEODYNAMICS 783 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
CALIBRATION BRUXELLES - FUNDAMENTAL STATION/NC50.4V/
INSTALLATION C.POITEVIN,E.RATTON
MAINTENANCE J.VANDERLIN,E.DE OLIVEIRA COSTA,J.E.ALBUQUERQUE

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 3/ 1

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .95099
PHASE LAG O1 .337 M2 .647 O1/M2 .521
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.00282 /MODEL 2/

G783 84 5 4/84 518 84 522/84 6 1 84 6 5/84 621 84 628/84 7 2 84 7 5/84 7 7
G783 84 712/84 716 84 8 7/84 825 84 831/8410 4 8410 9/841017 841024/8411 9
G783 841113/841113 841117/841117

TIME INTERVAL 199.0 DAYS 3600 READINGS 12 BLOKS EFFICIENCY .75

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	3.99	.08	1.2266	.0260	.578	1.211	.22	-169.5
143.-145.	16	O1	19.63	.09	1.1539	.0050	-.610	.251	.23	66.2
152.-155.	15	NO1	1.50	.06	1.1240	.0456	3.842	2.322	.11	-63.7
161.-163.	10	P1	9.06	.09	1.1447	.0119	.388	.591	.09	-40.7
164.-168.	23	S1K1	27.34	.09	1.1429	.0036	-1.810	.181	.87	97.4
175.-177.	14	J1	1.71	.08	1.2805	.0606	-2.926	2.692	.18	150.9
184.-186.	11	OO1	.79	.06	1.0755	.0832	-5.928	4.419	.11	50.7
233.-23X.	20	2N2	2.40	.05	1.1391	.0253	1.185	1.277	.07	132.1
243.-248.	24	N2	15.50	.07	1.1748	.0051	2.063	.245	.59	71.7
252.-258.	26	M2	80.43	.07	1.1676	.0010	1.611	.047	2.31	77.9
265.-265.	9	L2	2.28	.08	1.1705	.0393	4.521	1.925	.18	85.8
267.-273.	9	S2	37.56	.07	1.1720	.0021	1.191	.102	.87	64.5
274.-277.	12	K2	10.20	.06	1.1707	.0066	1.289	.322	.25	68.6
327.-375.	17	M3	1.44	.02	1.1095	.0188	1.412	.976	.06	33.2

STANDARD DEVIATION D 3.32 SD 2.42 TD .88 MICROGAL

QUALITY FACTORS : Q1= 5.3 Q2= 10.0
O1/K1 1.0097 1-O1/1-K1 1.0774 M2/O1 1.0118
CENTRAL EPOCH TJJ= 2445923.0

Table 12

TRANS WORLD PROFILE SOUTH AMERICA STATION CAICO

STATION 7311 CAICO RIO GRANDE DO NORTE COMPOSANTE VERTICALE BRESIL
06 31 33.6S 37 08 16.8W H 190M P 0M D 200KM
SEISMOLOGIC STATION CAICO,FAZENDA PIATO
SOCLE PRECAMBRIEN,GNEISS
UNIVERSIDADE FEDERAL DO RIO GRANDE DO NORTE - DEPARTAMENTO DE FISICA
TRANS WORLD TIDAL GRAVITY PROFILES P. MELCHIOR
CENTRO POLITECNICO-GEODESIA-U.F.PR. PROF. C.GEMAEL
GRAVIMETRE LA COSTE ROMBERG 8 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
ASSERVISSEMENT ELECTRONIQUE M. VAN RUYMBEKE
AJUSTEMENT DE LINEARITE PAR METHODE SATO-HARRISON
CALIBRATION CURITIBA STATION FONDAMENTALE
INSTALLATION C.POITEVIN,E.RATTON
MAINTENANCE FRANCISCO A. DOS SANTOS,JOSE MEDEIROS

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 2/21

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR 1.00247

G 8 841212/841226 841230/841230 85 1 5/85 125 85 128/85 128 85 210/85 212
G 8 85 217/85 3 3 85 3 6/85 322 85 329/85 4 2 85 4 6/85 418 85 422/85 518
G 8 85 522/85 7 7 85 711/85 717 85 721/85 729

TIME INTERVAL 230.5 DAYS 4656 READINGS 13 BLOKS EFFICIENCY .84

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	1.55	.08	1.1544	.0617	-7.590	3.074	.21	84.3
143.-145.	16	O1	7.72	.08	1.1015	.0115	-1.575	.598	.46	27.5
152.-155.	15	NO1	.69	.05	1.2607	.0927	5.040	4.200	.08	-131.3
161.-163.	10	P1	4.35	.09	1.3359	.0272	10.447	1.165	.95	-123.5
164.-168.	23	S1K1	11.62	.08	1.1794	.0083	4.292	.405	.95	-113.6
175.-177.	14	J1	.65	.08	1.1756	.1509	5.232	7.354	.06	-95.0
184.-186.	11	OO1	.38	.05	1.2639	.1776	4.409	8.048	.04	-135.7
233.-23X.	20	2N2	2.74	.05	1.2081	.0216	4.723	1.019	.25	66.2
243.-248.	24	N2	17.35	.06	1.2241	.0042	4.111	.195	1.51	55.2
252.-258.	26	M2	91.44	.06	1.2351	.0008	3.111	.037	7.34	42.5
265.-265.	9	L2	2.72	.08	1.3010	.0393	2.960	1.731	.32	25.8
267.-273.	9	S2	42.42	.06	1.2316	.0017	1.634	.076	2.73	26.3
274.-277.	12	K2	11.51	.05	1.2292	.0051	1.451	.236	.71	24.4
327.-375.	17	M3	1.60	.02	1.1111	.0160	.836	.819	.07	20.4

STANDARD DEVIATION D 3.68 SD 2.41 TD .96 MICROGAL

QUALITY FACTORS : Q1= 5.6 Q2= 12.2
O1/K1 .9339 1-O1/1-K1 .5655 M2/O1 1.1213
CENTRAL EPOCH TJJ= 2446161.0

Table 13

TRANS WORLD PROFILES SOUTH AMERICA STATION P. PRUDENTE 1

STATION 7312 P. PRUDENTE COMPOSANTE VERTICALE BRASIL
22 07 18 S 51 24 28 W H 430 M P 0M D 500KM 979 000 000
ARENITO DE FORMACAO BAURU - CRETACEO SUPERIOR
GRAVIMETRE LA COSTE ROMBERG 487 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
ASSERVISSEMENT ELECTRONIQUE M.VAN RUYMBEKE
AJUSTEMENT DE LINEARITE PAR METHODE SATO-HARRISON
CALIBRATION BRUXELLES - STATION FONDAMENTALE
INSTALLATION B. DUCARME, J. BITTENCOURT
MAINTENANCE J.C. BACH, J.F. GALERA, J.C. CHAVES

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
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COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 2/21

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .99641

G487 861121/861121 861125/87 126 87 130/87 3 3 87 3 9/87 319 87 324/87 4 5
G487 87 410/87 418 87 422/87 424 87 428/87 518 87 522/87 528

TIME INTERVAL 190.0 DAYS 4080 READINGS 9 BLOKS EFFICIENCY .89

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	4.82	.13	1.1618	.0321	-.296	1.581	.03	110.6
143.-145.	16	O1	25.40	.13	1.1732	.0061	-.949	.297	.51	125.2
152.-155.	15	NO1	1.83	.18	1.0747	.1056	10.516	5.608	.38	-62.5
161.-163.	10	P1	11.15	.15	1.1068	.0146	-.090	.757	.47	2.1
164.-168.	23	S1K1	34.70	.13	1.1394	.0044	.934	.221	.57	-95.2
175.-177.	14	J1	2.21	.13	1.3006	.0773	5.051	3.400	.30	-139.5
184.-186.	11	OO1	1.20	.10	1.2899	.1022	-2.097	4.533	.13	159.8
233.-23X.	20	2N2	2.34	.05	1.1887	.0253	1.516	1.214	.08	48.1
243.-248.	24	N2	14.48	.06	1.1741	.0051	.696	.250	.25	45.7
252.-258.	26	M2	75.29	.07	1.1692	.0010	.791	.051	1.19	61.0
265.-265.	9	L2	2.23	.06	1.2237	.0346	-1.755	1.617	.13	-30.8
267.-273.	9	S2	35.13	.06	1.1727	.0021	1.284	.100	.87	65.0
274.-277.	12	K2	9.36	.05	1.1482	.0059	.922	.294	.18	123.2
327.-375.	17	M3	1.32	.04	1.1284	.0377	1.121	1.888	.08	20.0

STANDARD DEVIATION D 6.03 SD 2.57 TD 1.70 MICROGAL

QUALITY FACTORS : Q1= 4.5 Q2= 9.6
O1/K1 1.0296 1-O1/1-K1 1.2419 M2/O1 .9966
CENTRAL EPOCH TJJ= 2446849.0

Table 14

TRANS WORLD PROFILE SOUTH AMERICA STATION TERESINA

STATION 7313 TERESINA PIAUI COMPOSANTE VERTICALE BRESIL
5 03 30 S 42 48 00 W H 70M P 0M D 350KM
FORMACAO SEDIMENTER - ARENINHO "PEDRA DO FOGO"
UNIVERSIDADE FEDERAL DE PIAUI - CENTRE DE TECNOLOGIA
DEP DE TRANSPORTES - CAMPUS ININGA
GRAVIMETRE GEODYNAMICS 783 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
CALIBRATION BRUXELLES - FUNDAMENTAL STATION/NC50.4V/
INSTALLATION C.POITEVIN,E.RATTON
MAINTENANCE J.L. SOUSA MENESES,A.A.REIS,J.O.MOURA

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 4/26

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .95099
PHASE LAG O1 .337 M2 .647 O1/M2 .521
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.00282 /MODEL 2/

G783 86 820/86 9 9 86 913/86 923 86 930/8610 2 8610 6/861010 861013/861029
G783 8611 6/8611 8 861118/861120 861126/861128 8612 1/861227 87 1 4/87 120
G783 87 124/87 3 3 87 312/87 320 87 327/87 4 6 87 411/87 421 87 522/87 530
G783 87 6 6/87 612 87 620/87 620

TIME INTERVAL 306.0 DAYS 5136 READINGS 17 BLOKS EFFICIENCY .70

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
127.-129.	11	SIGMA1	.34	.06	2.0263	.3417	-29.729	9.662	.20	120.8
133.-136.	20	Q1	1.01	.07	.9720	.0631	-3.012	3.710	.20	15.1
137.-139.	10	RO1	.28	.05	1.4347	.2474	24.296	9.857	.12	-104.1
143.-145.	16	O1	6.08	.05	1.1168	.0096	-1.923	.493	.31	41.0
152.-155.	15	NO1	.47	.04	1.0983	.0866	5.022	4.522	.05	-56.1
161.-163.	10	P1	3.01	.06	1.1867	.0253	-2.326	1.219	.15	123.7
164.-164.	3	S1	.60	.10	10.0413	1.6469	149.827	9.339	.54	146.2
165.-168.	20	K1	8.79	.06	1.1467	.0075	2.057	.376	.32	-101.5
175.-177.	14	J1	.46	.11	1.0802	.2462	-11.784	13.047	.10	64.8
184.-186.	11	OO1	.32	.04	1.3495	.1521	13.789	6.440	.08	-115.0
233.-236.	10	2N2	2.34	.04	1.2389	.0207	3.093	.954	.19	41.0
237.-23X.	10	MU2	2.69	.04	1.1842	.0170	5.780	.823	.27	81.4
243.-245.	13	N2	17.44	.04	1.2240	.0026	3.665	.123	1.42	51.9
246.-248.	11	NU2	3.30	.04	1.2190	.0138	4.388	.645	.29	59.3
252.-258.	26	M2	91.95	.04	1.2357	.0005	2.470	.023	6.81	35.6
265.-265.	9	L2	2.62	.03	1.2445	.0135	1.753	.623	.19	24.4
267.-272.	5	T2	2.51	.04	1.2385	.0177	.518	.823	.16	8.1
273.-273.	4	S2	42.50	.04	1.2274	.0011	1.326	.049	2.52	23.0
274.-277.	12	K2	11.52	.03	1.2234	.0029	1.204	.134	.64	22.2
327.-375.	17	M3	1.61	.02	1.1054	.0150	.590	.776	.06	16.7

STANDARD DEVIATION D 2.74 SD 1.59 TD .93 MICROGAL

QUALITY FACTORS : Q1= 6.7 Q2= 15.9
O1/K1 .9739 1-O1/1-K1 .7961 M2/O1 1.1064
CENTRAL EPOCH TJJ= 2446815.0

Table 15

TRANS WORLD PROFILE SOUTH AMERICA STATION VASSOURAS

STATION 7314 VASSOURAS - RJ COMPOSANTE VERTICALE BRESIL
22 24 01 S 43 39 05W H 468M P 0M D 80KM
UNDERGROUND CONCRETE CASEMATE
OBSERVATORIO MAGNETICO DE VASSOURAS
GRAVIMETRE GEODYNAMICS 783 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
CALIBRATION BRUXELLES - FUNDAMENTAL STATION/NC50.4V/
INSTALLATION C.POITEVIN,E.RATTON
MAINTENANCE LUIZ C. CARVALHO

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 3/ 2

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .95099
PHASE LAG O1 .337 M2 .647 O1/M2 .521
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.00282 /MODEL 2/

G783	87 629/87 7 1	87 712/87 714	87 725/87 8 6	87 813/87 827	87 831/87 9 4
G783	87 9 8/87 910	87 914/87 914	8710 3/8710 3	8710 7/8710 7	871015/871027
G783	8711 2/8711 2	871115/871125	871129/8712 7	871211/871231	88 1 3/88 1 9
G783	88 324/88 324	88 4 3/88 417	88 422/88 6 9		

TIME INTERVAL 348.0 DAYS 4560 READINGS 18 BLOKS EFFICIENCY .55

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
127.-129.	11	SIGMA1	.81	.08	1.2138	.1247	-3.006	5.905	.06	129.5
133.-136.	20	Q1	5.08	.08	1.2137	.0191	-1.920	.902	.28	142.8
137.-139.	10	RO1	.97	.08	1.2228	.0996	5.549	4.668	.10	-116.0
143.-145.	16	O1	25.66	.08	1.1734	.0035	-2.171	.173	1.01	106.6
152.-155.	15	NO1	2.17	.07	1.2629	.0430	-3.574	1.950	.22	142.3
161.-163.	10	P1	11.87	.09	1.1660	.0093	-.242	.453	.14	158.3
164.-164.	3	S1	.44	.13	1.8455	.5392	-151.153	17.085	.24	-117.6
165.-168.	20	K1	34.91	.08	1.1353	.0027	-.873	.136	.54	82.0
175.-177.	14	J1	1.97	.08	1.1430	.0464	-.801	2.328	.04	40.9
184.-186.	11	OO1	1.06	.05	1.1203	.0552	-2.059	2.823	.05	44.4
233.-236.	10	2N2	1.93	.07	1.1853	.0437	-.274	2.120	.04	-12.7
237.-23X.	10	MU2	2.28	.08	1.1602	.0391	2.962	1.919	.12	91.4
243.-245.	13	N2	14.71	.07	1.1976	.0058	1.552	.279	.60	41.2
246.-248.	11	NU2	2.80	.07	1.1992	.0318	.602	1.519	.10	17.9
252.-258.	26	M2	75.99	.07	1.1847	.0011	2.012	.053	3.08	60.2
265.-265.	9	L2	2.23	.09	1.2326	.0491	4.930	2.286	.23	57.3
267.-272.	5	T2	2.08	.07	1.1932	.0412	3.742	1.969	.15	68.6
273.-273.	4	S2	35.21	.07	1.1799	.0024	1.802	.113	1.25	62.6
274.-277.	12	K2	9.52	.06	1.1726	.0070	1.941	.340	.34	73.4
327.-375.	17	M3	1.30	.03	1.1153	.0270	1.048	1.368	.06	23.1

STANDARD DEVIATION D 3.66 SD 2.80 TD 1.26 MICROGAL

QUALITY FACTORS : Q1= 3.4 Q2= 7.4
O1/K1 1.0336 1-O1/1-K1 1.2816 M2/O1 1.0096
CENTRAL EPOCH TJJ= 2447148.0

Table 16

TRANS WORLD PROFILE SOUTH AMERICA STATION MANAUS

STATION 7315 MANAUS COMPOSANTE VERTICALE BRESIL
3 10 S 59 50 W H 40 M P 0 M D 1250 KM
UNIVERSIDADE DO AMAZONAS @ DEPARTAMANTO DE GEOCIENCIAS
ARENITE,GROUPE BARREIRAS,200M SUR SOCLE GRANITIQUE
GRAVIMETRE LA COSTE ROMBERG 3 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
ASSERVISSEMENT ELECTRONIQUE M. VAN RUYMBEKE
AJUSTEMENT DE LINEARITE PAR METHODE SATO-HARRISON
CALIBRATION CURITIBA STATION FONDAMENTALE
INSTALLATION C.POITEVIN,E.RATTON
MAINTENANCE A.MOURA TAVARES

UNESCO CONTRACT SC/RP203105.5

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 4/19

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .98846

G 3 85 719/85 719 85 726/85 726 85 8 9/85 8 9 85 815/85 819 85 826/85 9 5
G 3 85 910/851018 851023/851031 8511 6/851122 851127/851129 8512 3/8512 5
G 3 8512 9/851219 851225/851231 86 123/86 129 86 216/86 226 86 3 6/86 3 8

TIME INTERVAL 233.5 DAYS 3456 READINGS 15 BLOKS EFFICIENCY .62

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	1.26	.24	1.9200	.3673	-10.584	10.977	.53	154.1
143.-145.	16	O1	3.91	.20	1.1439	.0572	-5.319	2.868	.37	79.2
152.-155.	15	NO1	.15	.09	.5701	.3514	-37.310	35.309	.21	26.1
161.-163.	10	P1	2.92	.22	1.8320	.1390	-5.829	4.330	1.11	164.5
164.-168.	23	S1K1	5.57	.20	1.1573	.0420	10.343	2.077	1.00	-90.2
175.-177.	14	J1	.39	.26	1.4659	.9634	64.117	37.599	.38	-68.4
184.-186.	11	OO1	.16	.12	1.1014	.8406	60.280	43.369	.17	-57.3
233.-23X.	20	2N2	2.73	.07	1.1937	.0290	3.608	1.386	.19	67.4
243.-248.	24	N2	16.79	.09	1.1730	.0060	.467	.289	.23	36.7
252.-258.	26	M2	87.60	.09	1.1716	.0011	.451	.056	1.10	38.9
265.-265.	9	L2	2.34	.09	1.1061	.0416	.415	2.155	.12	171.6
267.-273.	9	S2	42.06	.08	1.2091	.0024	1.322	.111	1.95	29.8
274.-277.	12	K2	11.37	.07	1.2019	.0070	.123	.333	.40	3.5
327.-375.	17	M3	1.54	.04	1.0488	.0242	-.588	1.318	.03	-149.9

STANDARD DEVIATION D 7.70 SD 2.99 TD 1.26 MICROGAL

QUALITY FACTORS : Q1= 2.6 Q2= 4.8
O1/K1 .9884 1-O1/1-K1 .9150 M2/O1 1.0242
CENTRAL EPOCH TJJ= 2446382.0

Table 17

TRANS WORLD PROFILE SOUTH AMERICA STATION BELEM

STATION 7316 BELEM COMPOSANTE VERTICALE BRESIL
1 30 S 48 30 W H 4 M P 0M D 150 KM
INSTITUTO DE GEOFISICA - UNIVERSIDADE DO PARA
GRAVIMETRE GEODYNAMICS 783 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
CALIBRATION BRUXELLES - FUNDAMENTAL STATION/NC50.4V/
INSTALLATION C.POITEVIN,E.RATTON
MAINTENANCE LOURENILDO B.LEITE,A.LEANDRO MELO

UNESCO CONTRACT SC/RP203105.5

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 3/ 2

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .95099
PHASE LAG O1 .337 M2 .647 O1/M2 .521
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.00282 /MODEL 2/

G783 85 726/85 8 7 85 810/85 824 85 828/85 917 85 926/8510 2 8510 6/851026
G783 851030/8511 5 851110/851120 851124/851218 851227/86 1 6 86 110/86 122
G783 86 128/86 2 7

TIME INTERVAL 198.5 DAYS 3984 READINGS 11 BLOKS EFFICIENCY .84

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	.26	.09	.8326	.2830	-39.505	19.454	.23	45.7
143.-145.	16	O1	1.47	.07	.9058	.0409	9.207	2.583	.49	-28.7
152.-155.	15	NO1	.14	.02	1.1269	.1517	18.156	7.729	.05	-75.9
161.-163.	10	P1	1.27	.08	1.6762	.1020	37.336	3.488	.78	-100.0
164.-168.	23	S1K1	1.84	.07	.8050	.0310	16.543	2.198	.99	-32.1
175.-177.	14	J1	.16	.05	1.2721	.3867	-1.228	17.346	.01	166.1
184.-186.	11	OO1	.05	.04	.6643	.5489	9.262	47.349	.04	-12.0
233.-23X.	20	2N2	2.63	.12	1.1464	.0532	7.819	2.661	.36	98.9
243.-248.	24	N2	17.43	.15	1.2147	.0106	4.717	.508	1.61	63.2
252.-258.	26	M2	90.23	.15	1.2039	.0020	3.719	.097	6.62	62.1
265.-265.	9	L2	2.63	.15	1.2393	.0716	5.789	3.323	.31	59.7
267.-273.	9	S2	41.73	.14	1.1968	.0041	3.723	.195	2.96	66.2
274.-277.	12	K2	11.68	.11	1.2312	.0121	2.856	.564	.88	41.4
327.-375.	17	M3	1.58	.03	1.0726	.0224	2.796	1.202	.08	85.7

STANDARD DEVIATION D 3.06 SD 5.80 TD 1.27 MICROGAL

QUALITY FACTORS : Q1= 4.0 Q2= 8.3
O1/K1 1.1252 1-O1/1-K1 .4829 M2/O1 1.3291
CENTRAL EPOCH TJJ= 2446371.0

Table 18

TRANS WORLD PROFILE SOUTH AMERICA STATION SALVADOR

STATION 7317 SALVADOR DE BAHIA COMPOSANTE VERTICALE BRESIL
12 58 S 38 29 W H 15 M P 0 M D 1 KM
GRAVIMETRE LA COSTE ROMBERG 8 P.MELCHIOR - OBSERVATOIRE ROYAL DE BELGIQUE
ASSERVISSEMENT ELECTRONIQUE M. VAN RUYMBEKE
AJUSTEMENT DE LINEARITE PAR METHODE SATO-HARRISON
CALIBRATION CURITIBA STATION FONDAMENTALE
INSTALLATION POITEVIN - RATTON
MAINTENANCE SAMPAIO - CARVALHO - MENDOUCA - MARTIUS DA SILVA

UNESCO CONTRACT SC/RP203105.5

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
DATA PROCESSING L.VANDERCOILDEN / S.FREITAS
COMPUTER SPERRY-UNIVAC 1100/81 PROCESSED ON 90/ 2/22

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR 1.00247

G 8 85 8 6/85 8 8 85 814/85 814 85 827/85 827 85 831/85 914 85 917/85 917
G 8 85 924/85 928 8510 2/8510 4 851011/851011 851017/8511 4 8511 8/8511 8
G 8 851114/8512 8 86 128/86 130 86 3 5/86 3 5 86 320/86 411 86 415/86 427
G 8 86 5 6/86 518

TIME INTERVAL 287.0 DAYS 3456 READINGS 16 BLOKS EFFICIENCY .50

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	2.92	.13	1.1249	.0513	-3.823	2.610	.22	63.7
143.-145.	16	O1	15.26	.12	1.1249	.0087	-2.151	.445	.75	50.2
152.-155.	15	NO1	1.20	.10	1.1213	.0933	-2.543	4.739	.07	52.2
161.-163.	10	P1	7.14	.14	1.1315	.0216	.149	1.083	.14	-7.6
164.-168.	23	S1K1	21.38	.12	1.1205	.0066	.996	.335	.50	-48.4
175.-177.	14	J1	1.11	.14	1.0373	.1312	10.535	7.197	.25	-53.3
184.-186.	11	OO1	.81	.08	1.3902	.1406	-7.558	5.838	.17	140.0
233.-23X.	20	2N2	2.62	.05	1.2048	.0226	5.156	1.073	.25	69.8
243.-248.	24	N2	16.60	.06	1.2174	.0048	4.101	.224	1.40	58.1
252.-258.	26	M2	86.52	.07	1.2146	.0010	3.870	.046	6.91	57.7
265.-265.	9	L2	2.58	.09	1.2800	.0446	2.212	1.990	.26	22.6
267.-273.	9	S2	40.23	.08	1.2137	.0023	2.163	.107	2.32	41.0
274.-277.	12	K2	11.00	.06	1.2209	.0067	2.467	.312	.72	41.4
327.-375.	17	M3	1.48	.03	1.0840	.0198	.223	1.046	.02	14.2

STANDARD DEVIATION D 4.11 SD 2.37 TD .94 MICROGAL

QUALITY FACTORS : Q1= 3.2 Q2= 5.6
O1/K1 1.0039 1-O1/1-K1 1.0366 M2/O1 1.0798
CENTRAL EPOCH TJJ= 2446426.0

Table 19

STATION 7306 APPAREIL 32
COMPOSANTE V

SANTA MARIA R.GRANDEBRESIL -29.67140 -53.82280 700. 0. 300. 979252.*

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	1.1526	-2.26	.24	80.3	.18	173.9	.31	44.0	1.1165	-2.18	1.1955	-.19	5.11
O1	1.1567	-1.40	.76	84.1	.68	163.4	.92	37.4	1.1320	-1.06	1.1839	-.35	26.71
P1	1.1316	-2.91	.77	67.8	.15	155.7	.78	57.0	1.1207	-2.68	1.1644	-.24	12.43
K1	1.1181	-1.53	1.35	56.3	.44	150.9	1.45	38.8	1.1077	-1.25	1.1478	-.28	37.57
N2	1.1746	-.09	.16	-7.6	.29	11.7	.15	-147.7	1.1484	-.37	1.1864	.26	10.85
M2	1.1541	.25	.45	139.5	.80	40.1	.98	-166.8	1.1432	-.20	1.1710	.45	56.67
S2	1.1534	.15	.19	155.3	.45	117.7	.32	-83.2	1.1616	-.60	1.1522	.76	26.36
K2	1.1811	-.76	.19	-37.0	.17	119.6	.35	-47.9	1.1934	-1.74	1.1487	1.01	7.18

Table 20

STATION 7307 APPAREIL 3
COMPOSANTE V

C GRANDE MATTO G.BRESIL -20.46360 -54.61530 450. 0. 1000. 978491.*

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	1.3391	7.71	.96	-133.0	.08	167.1	.92	-128.8	1.3211	8.04	1.1791	-.22	3.89
O1	1.1405	-1.57	.75	58.5	.28	164.6	.87	40.4	1.1270	-1.41	1.1727	-.18	20.33
K1	1.0414	-3.54	3.36	33.2	.26	-179.8	3.57	30.9	1.0324	-3.56	1.1468	.00	28.60
N2	1.1290	1.25	.50	141.9	.32	50.6	.60	174.2	1.1128	.25	1.1764	.96	12.61
M2	1.1695	.72	1.15	57.8	1.31	58.0	.16	-120.7	1.1589	-.10	1.1708	.83	65.86
S2	1.2262	-.44	2.04	-8.1	.45	79.7	2.07	-20.7	1.2236	-1.12	1.1628	.72	30.64

Table 21

STATION 7309 APPAREIL 783
COMPOSANTE V

CUIABA MATTO G.BRESIL -15.60900 -56.12600 154. 0. 1882. 978044.*

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	1.1558	3.67	.23	-85.3	.04	159.4	.25	-76.4	1.1431	3.98	1.1726	-.24	3.08
O1	1.1745	-.62	.32	139.9	.15	168.1	.20	120.1	1.1657	-.54	1.1682	-.09	16.08
K1	1.1544	1.67	.84	-115.9	.22	-162.3	.70	-102.5	1.1448	1.52	1.1471	.15	22.62
N2	1.1742	1.74	.51	69.2	.38	59.4	.15	95.1	1.1592	.55	1.1749	1.20	13.32
M2	1.1757	1.11	1.92	56.1	1.57	57.2	.35	51.3	1.1632	.19	1.1725	.93	69.58
S2	1.1698	1.25	.88	69.8	.47	64.6	.42	75.4	1.1634	.62	1.1664	.64	32.37

Table 22

STATION 7310 APPAREIL 783
COMPOSANTE V

GOIANIA GOIAS BRESIL -16.62030 -49.25530 764. 0. 875. 978212.0

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	1.2266	.58	.22	-169.5	.07	133.0	.19	-152.2	1.2121	1.30	1.1738	-.74	3.26
O1	1.1539	-.61	.23	66.0	.19	121.7	.20	12.9	1.1478	-.13	1.1654	-.48	17.01
P1	1.1447	.39	.09	-40.8	.04	-149.2	.11	-22.5	1.1412	.26	1.1575	.11	7.92
K1	1.1429	-1.81	.87	97.5	.08	-155.6	.90	92.4	1.1398	-1.88	1.1407	.07	23.93
N2	1.1748	2.06	.59	71.8	.48	57.2	.17	115.8	1.1544	.59	1.1803	1.49	13.19
M2	1.1676	1.61	2.31	77.9	2.17	57.4	.81	147.7	1.1502	.31	1.1774	1.29	68.88
S2	1.1720	1.19	.87	64.4	.75	62.5	.12	76.7	1.1610	.19	1.1711	1.01	32.05
K2	1.1707	1.29	.25	68.6	.22	67.5	.03	75.6	1.1611	.18	1.1698	1.13	8.72

Table 23

STATION 7311 APPAREIL 8
COMPOSANTE V

CAICO R.GRANDEBRESIL -6.52600 -37.13800 190. 0. 200. 978062.

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	1.1559	-7.60	.21	84.9	.14	52.9	.12	123.7	1.2103	-3.45	1.0998	-4.33	1.34
O1	1.1015	-1.58	.46	27.5	.49	18.7	.08	134.2	1.1671	-.39	1.0935	-1.17	7.01
P1	1.3355	10.45	.95	-123.4	.18	-70.7	.85	-132.9	1.3457	8.20	1.1369	2.59	3.26
K1	1.1794	4.30	.95	-113.5	.51	-65.3	.72	-145.8	1.1986	1.96	1.1168	2.43	9.85
N2	1.2258	4.13	1.53	54.7	1.65	49.4	.19	-178.5	1.1467	-.02	1.2390	4.09	14.17
M2	1.2350	3.11	7.34	42.5	7.34	38.0	.58	130.8	1.1550	.29	1.2397	2.82	74.03
S2	1.2315	1.65	2.73	26.5	2.40	24.9	.34	38.1	1.1679	.30	1.2236	1.37	34.44
K2	1.2285	1.42	.70	24.1	.65	26.9	.06	-7.1	1.1666	-.04	1.2222	1.47	9.37

Table 24

STATION 7312 APPAREIL 487
COMPOSANTE V

P PRUDENTE S.PAULO BRESIL -22.12170 -51.40790 430. 0. 500. 978729.0

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	1.1618	-.30	.03	110.8	.11	157.1	.09	-8.4	1.1387	.16	1.1829	-.48	4.15
O1	1.1732	-.95	.52	125.3	.36	149.0	.23	86.8	1.1588	-.53	1.1735	-.42	21.66
P1	1.1068	-.09	.47	2.1	.07	169.1	.54	.4	1.1002	-.02	1.1605	-.07	10.08
K1	1.1394	.93	.57	-95.1	.20	162.2	.65	-77.3	1.1331	1.05	1.1440	-.10	30.46
N2	1.1741	.70	.25	45.7	.34	47.4	.09	-127.6	1.1557	-.28	1.1788	.98	12.33
M2	1.1692	.79	1.19	60.9	1.47	60.9	.28	-119.6	1.1580	-.19	1.1714	.98	64.39
S2	1.1727	1.28	.87	64.9	.60	83.1	.36	33.7	1.1700	.32	1.1626	.97	29.96
K2	1.1482	.92	.18	123.1	.19	88.2	.11	-160.5	1.1473	-.23	1.1610	1.14	8.15

Table 25

STATION 7313 APPAREIL 783
COMPOSANTE V

TERESINA PIAUI BRESIL -5.06000 -42.76600 70. 0. 350. 978017.*

ONDE	DELTA	ALFA	B	BETA	L	LAMBDA	X	CHI	DELTA	ALFA	DELTA	ALFA	AMPL
	OBSERVES								CORRIGES		MODELISES	SCW80	
Q1	.9720	-3.01	.20	15.1	.10	47.5	.13	-11.4	1.0422	1.30	1.0946	-3.85	1.04
O1	1.1168	-1.92	.31	41.0	.39	13.8	.18	143.1	1.1864	-.97	1.0896	-.90	5.45
P1	1.1867	-2.33	.15	123.7	.14	-64.2	.29	119.9	1.2144	-4.66	1.1308	2.51	2.54
K1	1.1467	2.06	.32	-101.5	.42	-55.4	.30	173.9	1.1771	-.21	1.1074	2.34	7.67
N2	1.2240	3.66	1.42	51.9	1.32	51.9	.10	52.3	1.1643	.27	1.2196	3.43	14.25
M2	1.2357	2.47	6.81	35.6	5.83	41.2	1.16	6.3	1.1756	.08	1.2201	2.42	74.41
S2	1.2274	1.33	2.52	23.0	1.77	27.8	.77	11.9	1.1818	.22	1.2057	1.14	34.62
K2	1.2234	1.20	.64	22.2	.47	28.8	.18	4.7	1.1791	.08	1.2042	1.15	9.42

Table 26

STATION 7314 APPAREIL 783
COMPOSANTE V

VASSOURAS RIO J. BRESIL -22.40030 -43.65150 468. 0. 80. 978691.

ONDE	DELTA	ALFA	B	BETA	L	LAMBDA	X	CHI	DELTA	ALFA	DELTA	ALFA	AMPL
	OBSERVES								CORRIGES		MODELISES	SCW80	
Q1	1.2137	-1.92	.28	142.8	.20	128.8	.10	170.5	1.1835	-.19	1.1894	-1.75	4.19
O1	1.1734	-2.17	1.01	106.6	.66	110.9	.36	98.5	1.1618	-.79	1.1704	-1.38	21.87
P1	1.1660	-.24	.14	158.3	.05	59.4	.16	177.9	1.1691	-.03	1.1510	-.23	10.18
K1	1.1353	-.87	.54	82.0	.19	53.5	.38	95.9	1.1390	-.62	1.1339	-.25	30.76
N2	1.1976	1.55	.60	41.2	.52	53.3	.14	-8.4	1.1716	-.08	1.1858	1.64	12.28
M2	1.1847	2.01	3.08	60.1	2.91	69.9	.53	-6.5	1.1684	-.05	1.1765	2.08	64.14
S2	1.1799	1.80	1.25	62.6	1.45	77.5	.40	-49.9	1.1689	-.51	1.1716	2.33	29.84
K2	1.1726	1.94	.34	73.4	.45	80.5	.12	-78.5	1.1630	-.69	1.1705	2.66	8.12

Table 27

STATION 7315 APPAREIL 3
COMPOSANTE V

MANAUS AMAZONASBRESIL -3.16600 -59.83300 40. 0. 1250. 978006.*

ONDE	DELTA	ALFA	B	BETA	L	LAMBDA	X	CHI	DELTA	ALFA	DELTA	ALFA	AMPL
	OBSERVES								CORRIGES		MODELISES	SCW80	
Q1	1.9200	-10.58	.53	154.1	.04	47.3	.54	158.0	1.9521	-9.13	1.1202	-2.23	.66
O1	1.1439	-5.32	.37	79.1	.13	11.9	.34	100.2	1.1810	-4.77	1.1215	-.41	3.42
P1	1.8320	-5.83	1.11	164.5	.04	-95.8	1.12	162.3	1.8350	-6.70	1.1568	1.37	1.59
K1	1.1573	10.34	1.00	-90.2	.11	-89.3	.89	-90.3	1.1534	9.20	1.1376	1.18	4.81
N2	1.1730	.47	.23	36.6	.56	70.3	.39	-90.8	1.1600	-1.36	1.1739	1.81	14.31
M2	1.1716	.45	1.10	38.8	2.38	56.1	1.36	-110.2	1.1539	-.85	1.1781	1.28	74.76
S2	1.2091	1.32	1.95	29.8	.61	41.1	1.36	24.8	1.1957	.78	1.1733	.56	34.78
K2	1.2019	.12	.40	3.5	.17	39.6	.28	-17.6	1.1884	-.43	1.1741	.56	9.47

Table 28

STATION 7316 APPAREIL 783
COMPOSANTE V

BELEM PARA BRESIL -1.50000 -48.50000 4. 0. 150. 978025.*

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	.8326	-39.51	.23	45.7	.11	34.4	.12	55.5	.9891	-19.56	.8926	-12.83	.31
O1	.9058	9.21	.49	-28.7	.47	6.8	.29	-97.0	1.1948	8.63	.8733	-2.25	1.62
P1	1.6762	37.34	.78	-100.0	.15	-51.2	.69	-109.1	1.6923	30.78	1.0435	8.30	.76
K1	.8050	16.54	.99	-32.1	.47	-41.8	.53	-23.5	.9280	5.78	.9942	7.92	2.28
N2	1.2147	4.72	1.61	63.2	1.34	56.5	.32	92.7	1.1593	1.09	1.2142	3.69	14.35
M2	1.2039	3.72	6.62	62.1	6.02	42.9	2.19	126.9	1.1428	1.17	1.2202	2.57	74.94
S2	1.1968	3.72	2.96	66.3	1.69	30.0	1.88	98.3	1.1535	2.65	1.2024	1.16	34.87
K2	1.2312	2.86	.88	41.4	.46	29.4	.44	53.8	1.1883	1.82	1.2023	1.13	9.49

Table 29

STATION 7317 APPAREIL 8
COMPOSANTE V

SALVADOR BAHIA BRESIL -12.96600 -38.48300 190. 0. 5. 978311.*

ONDE	DELTA OBSERVES	ALFA OBSERVES	B	BETA	L	LAMBDA	X	CHI	DELTA CORRIGES	ALFA CORRIGES	DELTA MODELISES SCW80	ALFA MODELISES SCW80	AMPL
Q1	1.1249	-3.82	.22	63.7	.15	83.4	.10	32.7	1.1287	-1.01	1.1543	-2.78	2.60
O1	1.1249	-2.15	.75	50.2	.55	54.6	.20	38.2	1.1475	-.46	1.1362	-1.67	13.57
P1	1.1315	.15	.14	-7.6	.12	-51.7	.10	50.4	1.1436	-.61	1.1418	.76	6.32
K1	1.1205	1.00	.50	-48.4	.36	-48.7	.14	-47.5	1.1327	.27	1.1252	73	19.08
N2	1.2174	4.10	1.40	58.1	1.39	58.8	.02	5.5	1.1617	.01	1.2158	4.10	13.64
M2	1.2146	3.87	6.90	57.7	6.82	51.4	.76	137.9	1.1522	.36	1.2222	3.51	71.23
S2	1.2137	2.16	2.31	41.0	2.53	42.5	.22	-121.4	1.1567	-.28	1.2175	2.43	33.14
K2	1.2209	2.47	.72	41.4	.68	46.1	.07	-15.0	1.1674	-.10	1.2139	2.58	9.02