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Automated Burris gravity meter for single and continuous observation

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ABSTRACT

The Burris Gravity Meter™ manufactured by ZLS Corporation, Austin/Texas, USA, is based on the invention of L&R (L. LaCoste and A. Romberg): The ZLS (zero-length spring). A digital feedback system (range of about 50 mGal) is used to null the beam. Now, more than 120 gravity meters of this make exist worldwide and are used successfully in exploration, volcanology, geodetic work and surveying.

The sensor is made of the well-known (L&R) metal-alloy zero-length spring providing a low drift characteristic. The drifts observed are comparable to L&R gravimeters and are less than 0.3 mGal per month, which is much lower than the drifts known for the fused quartz sensors.

The dial is calibrated every 50 mGal over the entire 7000 mGal meter range. Since the gravity value is determined at these points, there are no periodic errors. By a fourth heater circuit temperature effects are totally avoided. The gravity meter is controlled via Bluetooth® either to a handheld computer (tablet) or a notebook computer.

The feedback responds with high stability and accuracy. The nulling of the beam is controlled by the UltraGrav™ control system which incorporates an inherently linear PWM (pulse-width modulated) electrostatic feedback system. In order to improve the handling of the gravimeter we have developed two Windows based programs: AGESfield for single measurements and AGEScont for continuous readings.

1. Introduction

The Burris Gravity Meter™ manufactured by ZLS Corporation, Austin/Texas, USA, is based on the invention of L. LaCoste and A. Romberg: The zero-length spring [1]. The sensor is made of the well-known (L&R) metal-alloy *zero-length spring* because of its low drift characteristics. The drifts observed are comparable to L&R gravimeters and are less than 0.3 mGal[2] per month. Thus, they are much lower than the drifts known for the fused quartz sensors [2]. A digital feedback system (range of about 50 mGal) is used to null the beam. With the help of a dial the measuring range can be adjusted. The dial is calibrated every 50 mGal over the entire 7000 mGal meter range. Taking readings at these points avoids periodic errors. The feedback responds with high stability and accuracy. The nulling of the beam is controlled by the UltraGrav™ control system which incorporates an inherently linear PWM (pulse-width modulated) electrostatic feedback system [3–5].

In order to improve the handling of the gravimeter as well as to achieve a faster running-in we have developed two Windows based programs which serve for the same purpose: *AGESfield* for single measurements and *AGEScont* for continuous readings. This was started by the group of co-author Jentzsch [6]. The new systems allow the operation of a notebook computer with several advantages like large storage space, connection of GPS for

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[1] GRAVITY CONSULT GmbH is a company which emerged from the university research group of the first author; this company represents ZLS Corp. in Europe selling expertise and gravimeters as well as developing hardware.

[2] 1 mGal corresponds to 10^{-5} m/s^2.

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positioning and time as well as air pressure sensor, and simple data transfer.

By a fourth heater circuit, temperature effects are totally avoided. The gravity meter is controlled via Bluetooth® either to a handheld computer (tablet with UltraGrav™) or a notebook computer (with AGESfield or AGEScont).

Now, more than 120 gravity meters of this make (calibrated and non-calibrated screw) exist worldwide and are used successfully in exploration, volcanology, geodetic work and surveying.

2. Some technical features and experimental results

Due to the calibration of the screw (every 50 mGal over the entire 7000 mGal meter range) no circular errors are involved when measurements are within the range of the feedback system or at the calibrated points. The observed standard deviations are in the order of 3 μGal or better during routine field tests. More details are obtainable from ZLS (http://zlscorp.com/).

Calibrated ultra-miniature electronic levels are used for correction of horizontal misalignment to insure accurate and reliable and reproducible operation of the gravimeter. After adjustment of these levels the result can be incorporated into the control program to provide automatic correction.

The control software of ZLS as well as the software developed by us uses the feedback signal and the dial position (calibrated point) to calculate the gravity value.

The check of the feedback on the vertical calibration line in Hanover, Germany, provided reliable results below the 3 μGal level, and the accuracy of the calibration factor was 10^{-4} [5]. The observed drifts during field measurements are stable (comp. Fig. 1a and b). As can be seen, the drifts are small but a little different due to the fact that we have a mechanical system, the spring. But the stability is much better and the drift is much smaller than reported for the Scintrex meter [7].

The technical features are contained in Table 1. The gravimeter is available with the calibrated screw (worldwide range of 7000 mGal[3]) and the non-calibrated screw with the range of the

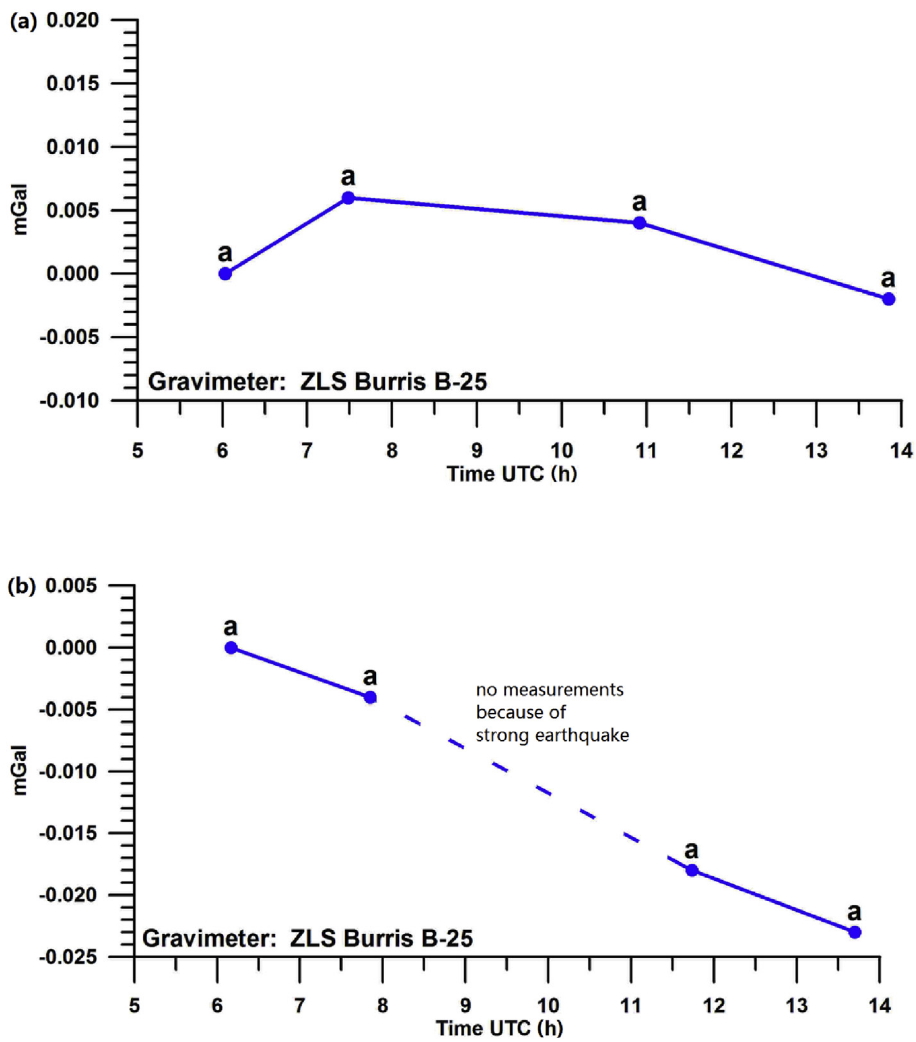

Fig. 1. a-Observations of September 03, 2013 shows the drift after many movements (great number of points and about 150 km car transport). The rounded negative drift rate is between 0.001 mGal/h and 0.002 mGal/h. Positive drift see text. The letter “a” denotes measurements at the base station. b-Daily drift of September 28, 2013, around an earthquake: There is no drift effect of the seismic waves to be seen; the rounded drift rate is −0.003 mGal/h. The letter “a” denotes measurements at the base station. (Both graphs modified after Jentzsch et al., [6]).

[3] Actually, depending on the screw, the usable range expands from about 250 to about 6750 mGal.

Table 1
The Burris Gravity Meter™ (Non-Calibrated and calibrated screw).

50 mGal Automatic Nulling Range with Microgal Reading Precision
Worldwide Ranging Screw
Land Gravity Meter with Beam Galvo
Electronic Levels with Reading Galvos
UltraGrav™ Electronics, Controller and Software
Calibrated Burris Gravity Meter™
7000 mGal Worldwide Range
Options:
Secular (Earth Tide) Meter: For precise earth-tide measurements the Non-Calibrated Burris Gravity Meter™ can be configured with less range for a higher internal resolution of 0.0002 mGal.

feedback of only ~50 mGal; this range corresponds to an elevation difference of about 250 m (using the Bouguer-corrected vertical gradient of about 0.2 mGal/m). Nevertheless, the gravimeter is useable all over the world if an additional reading and adjustment of the range with the dial is made.

The beam of the Burris Gravimeter is nulled by a fully digital, microprocessor-based automatic reading and data logging system (Table 2): UltraGrav™ is now installed on an Android tablet, connected for flexibility in the field via Bluetooth®. When new, ZLS springs drift ~1.0 mGal per month, and when mature, typically less than 0.3 mGal per month. According to ZLS the prototype shows a drift of ~0.030 mGal per month.

3. Observations

We will discuss some results obtained for survey measurements (single mode) and continuous recording.

3.1. Single mode

The typical behavior of metal-spring- gravimeters at the beginning of the measurement is a positive drift. This can be prevented by a correct gravimeter-handling. This correct handling has to be adapted to the individual gravimeter. The negative drift rate (correct drift) is very smooth and obviously not affected by the car transport (Fig. 1a).

Table 2
Gravity Meter Sensor Design and Features (from ZLS homepage).

UltraGrav™:
An inherently linear pulse-width modulated (PWM) electrostatic feedback control system to automatically null the beam [3]. The Low power feedback system automatically produces an electrostatic feedback signal from the output voltage of the capacitive position transducer.
Range of the feedback system: ± 25 mGal.
Ceramic Electronic levels used to insure accurate and reliable gravity measurements (orthogonally mounted on the sensor, resolution of one arc-second). They can be calibrated and used for automatic correction.
Meter operation in ambient temperature ranging from −15 to +50 °C.
Sensor
Type: Metal Zero-Length Spring Hardened metal micrometer screw
Range: 7000 mGal
Temperature range: −15 to +50 °C
Electronic Levels
Range: +/− 2 arc-minutes (4 arc-minutes total)
Resolution: 1 asec
Reading Resolution
single reading mode: 0.001 mGal
Continuous reading mode (filtered): 0.0001 mGal
Precision of Calibrated Points (Calibrated Screw Meters Only)
Standard: better than +/− 0.015 mGal
Data Repeatability (Under normal conditions of background noise)
Within 50 mGal: 0.005–0.007 mGal (Feedback)
Over 50 mGal: +/− 0.015 mGal (Screw)
Drift
When New: Approximately 1.0 mGal per month after aging
When Mature: Less than 0.3 mGal per month

Fig. 1b shows the drift with a correct handling and in addition the behavior during an earthquake. Just before the arrival of the seismic waves and directly after measurements at the base station were carried out to control the effect of the shaking, but there is nothing to see. These measurements were carried out with the ZLS – program UltraGrav™.

3.2. Continuous mode

We tested B-25 in the Geodynamic Observatory Moxa of the University of Jena. There, we carried out several records of different lengths to observe the drift as well as to analyze the tidal parameters. For this purpose we developed a recording system to avoid the problems created by the PDA[4] regarding exact time and limited memory capacity, as well as lacking input sockets for time signal and air pressure. Fig. 2 shows the flow chart of this system. Although B-25 is not a specific Earth Tide meter, the results concerning low drift and high resolution are quite remarkable. The recording program used was FSU-Grav, developed at the Institute for Geosciences in Jena [5].

The following Figs. 3–5 show a longer record, as well as the section of an earthquake and the exited free modes, revealing the

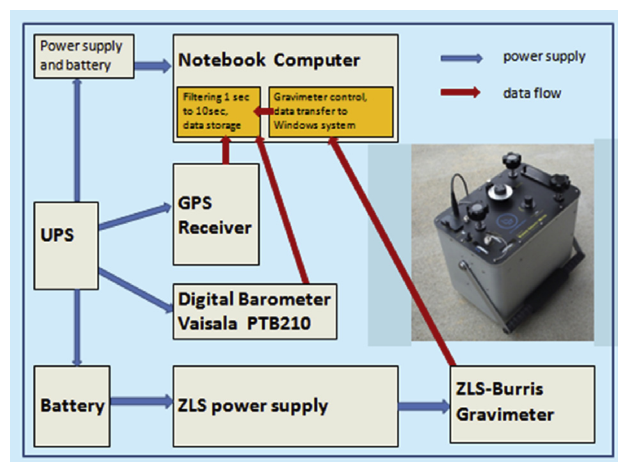

Fig. 2. Flow chart of the recording system and components (modified after Jentzsch [5]).

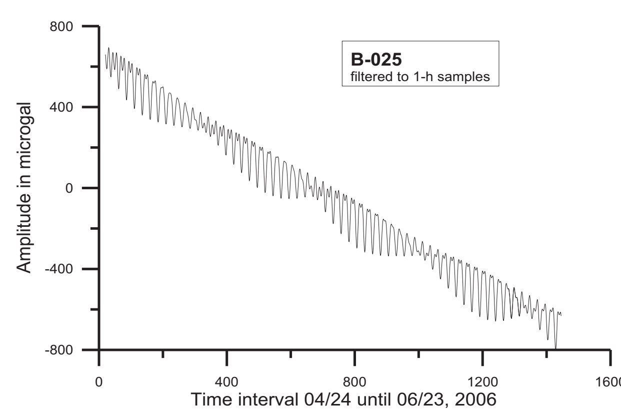

Fig. 3. First long interval of the record in the Geodynamic Observatory Moxa from April 24 to June 23, 2006: Note nearly linear drift of about −0.62 mGal per month. Data are filtered to 1-h samples (from Jentzsch [5]).

[4] Now replaced by the Android tablet.

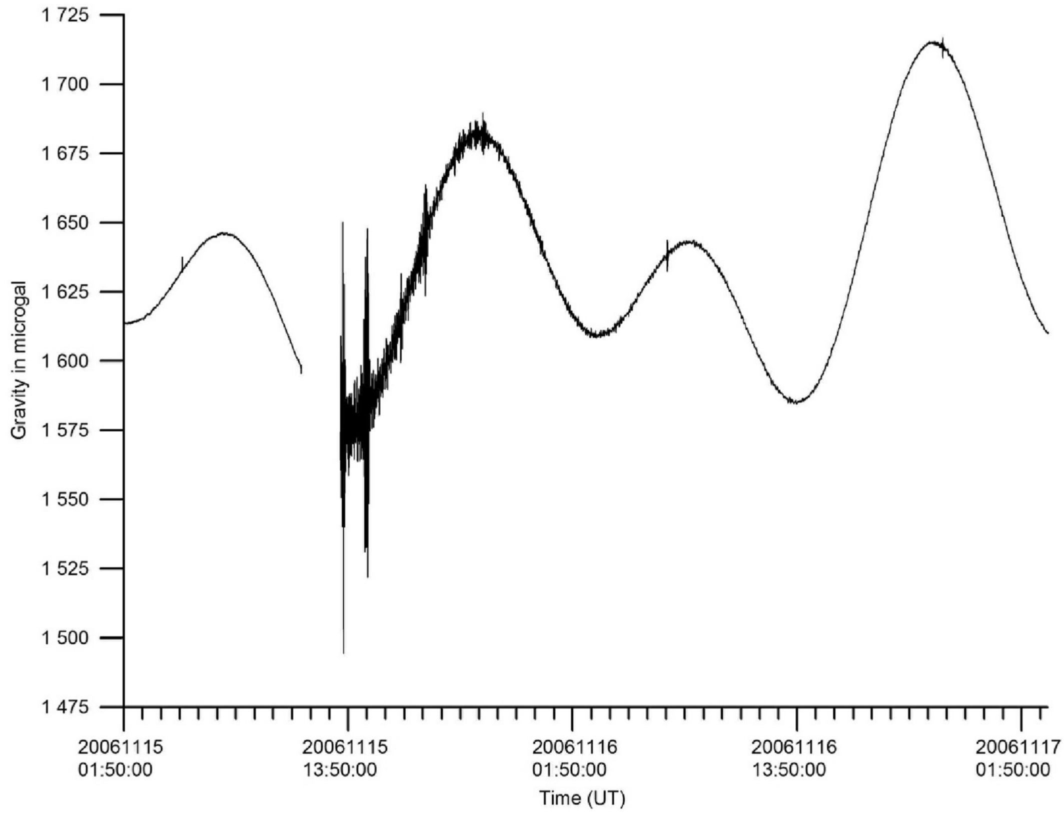

Fig. 4. Record Earthquake, Kuril Islands: Nov. 15, 2006, 11:14:17 UTC, Mw = 8.3. The start of the record is omitted because of the oversaturation due to the large amplitudes (modified after Jentzsch [5]).

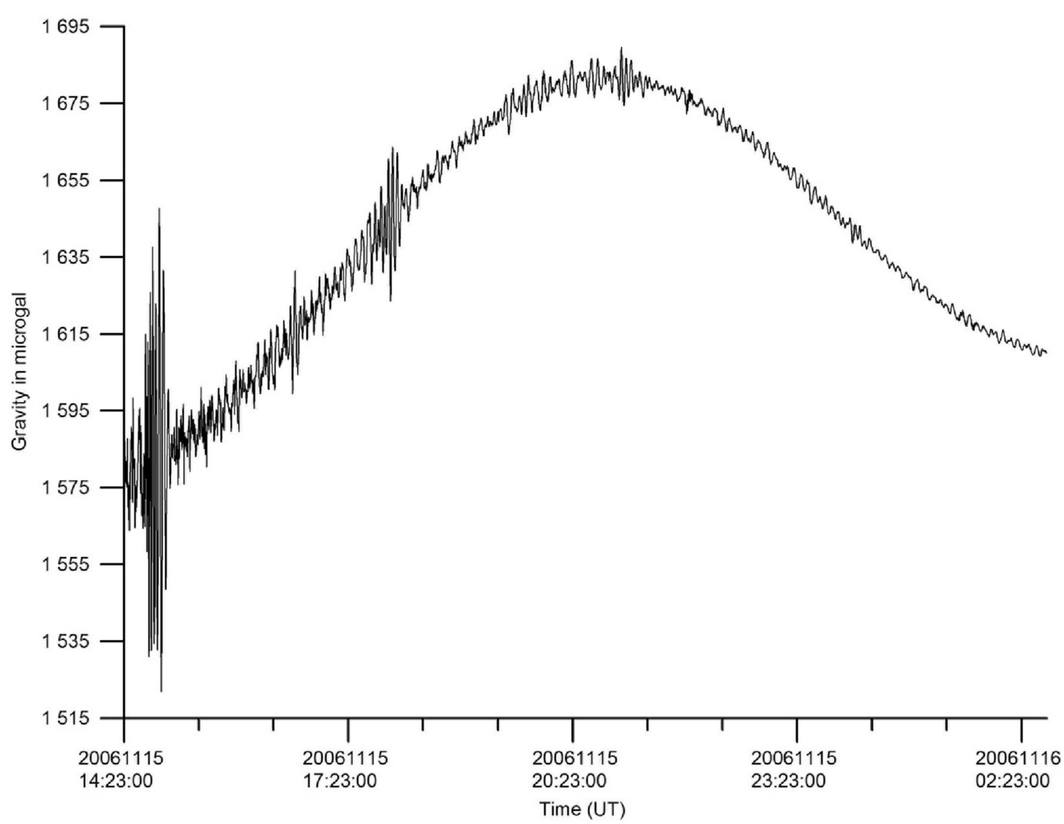

Fig. 5. Section of earthquake record (Fig. 4) showing free modes (modified after Jentzsch [5]).

quality of the measurements. Table 3 gives the obtained tidal parameters, including estimated noise from the tidal analysis using the software package ETERNA [8].

The free-modes record is dominated by the long-period signals having periods of around 1 h, half an hour and 20 min.

4. Conclusions

As can be seen, the gravimeter provides reliable results both for single as well as continuous observations on a high level. In a separate paper, co-author Schulz [11]. Describes his control systems AGESfield and AGEScont of the gravimeter which replaces the control system of ZLS. This system is very comprehensive and covers not only the use of the gravimeter (control, maintenance, high resolution coordinates, data transfer) but also the organization of the data (different projects, observers). This provides advantages concerning the use of the gravimeters in different projects and surveys, esp. in micro-gravity, and in handling the gravimeter. Schilling and Gitlein [12] compare the Burris B-64 m with their Micro-g LaCoste gPhone-98 in different stations and find a very good coherence with the superconducting gravimeter (OSG-054) in Onsala.

Table 3
Results of the tidal analysis after Jentzsch [5].

Summary of observation data	
Number of recorded days in total: 76.96	
Hartmann + Wenzel [9] tidal potential used with threshold 0.10E-06	
WAHR-DEHANT-ZSCHAU inelastic Earth model used [10].	
Inertial correction not applied	
Spectral condition number of normal equations: 1.907	
Estimation of noise by FOURIER-spectrum of residuals	
0.1 cpd band	– nm/s^2
1.0 cpd band	0.4830 nm/s^2
2.0 cpd band	0.2392 nm/s^2
3.0 cpd band	0.2159 nm/s^2
4.0 cpd band 0.2101 nm/s^2	white noise 0.2479 nm/s^2

Adjusted tidal parameters

From(cpd)	To(cpd)	Wave	Ampl(nm/s^2)	ampl.fac	stdv	Phase lead (deg)	stdv. (deg)
0.501370	0.911390	Q1	66.7735	1.14420	0.00489	0.112	0.2453
0.911391	0.947991	O1	349.6408	1.14712	0.00080	0.166	0.0399
0.947992	0.981854	M1	27.4979	1.14771	0.00839	0.423	0.4174
0.981855	1.023622	K1	486.7218	1.13590	0.00054	0.344	0.0273
1.023623	1.057485	J1	27.9823	1.16751	0.01216	0.996	0.5977
1.057486	1.470243	OO1	15.1176	1.15322	0.01213	0.353	0.6027
1.470244	1.880264	2N2	10.7858	1.16661	0.02092	0.422	1.0258
1.880265	1.914128	N2	68.3776	1.18120	0.00297	1.815	0.1444
1.914129	1.950419	M2	357.9534	1.18394	0.00048	1.579	0.0231
1.950420	1.984282	L2	9.9843	1.16822	0.01688	0.536	0.8259
1.984283	2.451943	S2	167.2546	1.18914	0.00107	1.040	0.0515
2.451944	7.000000	M3	3.8431	1.01916	0.03320	2.689	1.8656

Degree of freedom: 1723.
Standard deviation: 4.256 nm/s^2.

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Based on programs developed by the first author (GJ) and his group the second author (RS) modified and improved these programs considerably to extend their application. Special thanks to Andreas Hoffmann who did most of the programming work in Jena. We also thank the staff of the company ZLS Corp. for providing information and support to carry out all these developments.

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* Completion of professor thesis (Habilitation) in 1985
* Professor for Applied Geophysics, Geological Institute, University of Bonn, 1987 to 1990
* Professor for Geophysics, Institute for Geophysics, Technical University of Clausthal, 1990 to 1996
* Visiting scientist at the Institute for Earthquake Research, University of Tokyo (with JSPS, 1996)
* Full Professor and Chair for Applied Geophysics, Institute for Geosciences, University of Jena (starting in 1996, retirement 2011)

(*continued*)

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- Earth tides and ocean tidal loading
- Gravity field analyses and stress/deformation modelling
- Seismicity and deformation
- Seismic hazard of nuclear installations
- Physical Volcanology

The department runs the Geodynamic Observatory Moxa and the East-Thuringia Seismological Network. The Geodynamic Observatory Moxa is equipped with a superconducting gravimeter, and, thus, belongs to the station network of the Global Geodynamics Project. It is also a station of the ECGN (European Combined Geodetic Network) and the GRSN (German Regional Seismic Network).

On the basis of the East-Thuringian Seismological Network he was involved in swarm earthquake evaluation, especially in the area Vogtland / NW-Bohemia.

He was member of the so-called Advisory Board for the Termination of Nuclear Energy Use (Provincial Ministry for the Environment in Lower Saxony), and member of the German siting committee to develop a procedure for the search for a site for the German nuclear repository (German Federal Ministry of the Environment, 1999 to 2002), from 2009 to 2013 he was member of the Nuclear Waste Management Commission of the same Federal Ministry. Since 1990 he was involved in the estimation of earthquake hazards for different nuclear power plants and companies handling nuclear material in Germany, Czech Republic, France and USA.

He was active in national and international scientific organisations: Organisation of several special sessions at international meetings; chairman of different working groups of the Earth Tide Commission of the IAG, organising several workshops over 20 years; co-operations with foreign scientists, China and Japan (starting in 1986), Fennoscandia, Russia, Hungary, Poland; appointment as Fellow of the IAG in 1991; he was President of the German Geophysical Society and President of the FKPE, the Board of German Geophysical Institutions; he was the President of the Earth Tides Commission of the IAG (two terms 2003 to 2007 and 2007 to 2011).

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