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BULLETIN D'INFORMATIONS

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CENTRE INTERNATIONAL DES MARÉES TERRESTRES

Federation of Astronomical and Geophysical Data Analysis Services
(FAGS)

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The precious help of Prof. Bernard Ducarme is gracefully acknowledged for his guidance and help in completing this issue of the BIM.

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BIM n°144

15 décembre 2008

New Challenges in Earth Dynamics (ETS2008)

Scientific papers

Prorector Prof. Dr. Herbert Witte

Dear participants!

The place Jena has a long tradition in Earth sciences, starting before the year 1900 with the construction of a seismological station and the installation of a seismograph. The station started to record seismic signals in March 1900. During those days, after the foundation of the first Geophysical Institute at the University of Göttingen in 1898, the name ***Geophysics*** still was not yet widely known, and the branch ***Seismology*** was still growing. Jena was one of four places in Germany where seismology was developed (the others were Göttingen, Potsdam and Strasbourg).

In 1923 a very specific field was started by August Sieberg: Applied or Engineering Seismology. He had to move from Strasbourg to Jena and continued here his pioneering work in the classification of earthquake shaking (the letter S of the MCS seismic intensity scale relates to Sieberg, who improved the existing scale of Mercalli and Cancani in 1924). Later, this scale was again improved in 1964 and is still in use as MSK-scale, the letters pointing to Medvedev, Karník and Sponheuer, the former assistant of Sieberg. Later developments in Jena led to the construction of an underground seismic station some 30 km south of Jena, which started to work in 1964. During the past 12 years this station was further developed to become the comprehensive **Geodynamic Observatory Moxa**. Now, not only seismometers are in use but also deformation and gravity measurements are carried out there.

Looking at textbooks from the time about 100 years ago, e.g. from George Howard Darwin and August Sieberg, we realize that at this time the scope of seismology and the frequency range were much wider than today: Even telluric signals and brady-seismic signals were included – and here the circle closes in our observatory. But – as I realize – it also closes in your conference covering Earth tides and Earth rotation, as well as seismology and tectonics and geophysical fluids as indicators for underground activities like volcanism, or together with tectonic movements as driving forces for earthquakes.

As I understand, due to modern developments there is always a **New Challenge** – in so far the title of your symposium is correct. But looking at the history of your science, I consider that during the past century there was always a New Challenge in Earth's Dynamics, based on old questions and new insights leading to new questions and, thus, new challenges.

This year, the Friedrich-Schiller-University celebrates its 450th anniversary, and we have encouraged the scientists to frame this anniversary with congresses and meetings - not only to ornament the celebrations of our jubilee, but to demonstrate the local scientific abilities, both to our guests and to the public. Your symposium covers topics very much related to Jena, and it unites scientists from all over the world. Thus, it is a prominent contribution to the puzzle of the picture of our university. I am happy to welcome you in Jena! I wish you an interesting week at our university with good discussions, new findings and – finally - good memories to this place! Thank you for coming.

Herbert Witte

Dean Prof. Dr. Gerd Buntkowsky

Dear participants of the ETS 2008 in Jena !!!

As dean of the faculty of Chemistry and Geoscience of the Friedrich-Schiller-University it is my great pleasure to welcome you to here in Jena.

This year is very special for us. Our university celebrates its 450th anniversary and Jena was distinguished as City of Science 2008. We are very honored to host such a high ranking conference as the Earth Tide Symposium in this special year.

You have just heard some historical remarks about the development of Earth Sciences in Jena. Before handing you over to science, let me shortly inform you about the recent history of the Institute of Geoscience and the relation of Geosciences and our Faculty.

Our faculty comprises of Chemistry and Geosciences. This was not always the case. Despite of the long tradition of Geosciences and especially Geophysics in Jena, they were mostly no part of the university:

At the beginning, Seismology, including Applied Geophysics, formed an independent research institute of the government (called a *Reichsanstalt*, which you can think of as a national lab). This *Reichsanstalt* belonged later to the Academy of Sciences in Berlin, and moved to the Central Institute of Physics of the Earth in Potsdam. After the political changes in Germany, it was transformed to the Geo-Research-Center Potsdam.

Finally in 1992, the new Institute for Geosciences was founded as part of our university. It was allocated to the Faculty for Chemistry – maybe because of the existing related field: Environmental Chemistry. The focal point for the new Institute for Geosciences was the former outpost of the institute in Potsdam with the seismic observatory in Moxa.

In 1996 Prof. Jentzsch was appointed Chair of Applied Geophysics and moved to Jena – together with his group. His group was well known for the experiences in Earth Tides, crustal deformation and gravity field analyses. To fulfill the needs for a more comprehensive understanding of geophysics, they not only modernized the observatory in Moxa but they also installed a seismic network in East-Thuringia. The latter is a clandestine earthquake area (at least according to Prof. Jentzsch).

The local earthquake catalogue goes back to the year 1323 with an earthquake intensity of nearly 7 (local magnitude derived: about 5).

By the way, the last big earthquake in this area occurred in 1872 with an intensity of 7.5. The damage done by it can still be seen at the castle Posterstein. The most recent earthquake that shocked part of East-Thuringia with an intensity of over 5 and a magnitude of more than 3 occurred on October 19, 2007.

I wish you an earthquake-free and interesting week in Jena! Enjoy the charm of our small city and the hospitality of our faculty!

Gerd Buntkowsky

Dr. Albrecht Schröter

Ladies and gentlemen, dear guests,

as the mayor of the City of Jena I am very proud of welcoming you today. On behalf of the citizens of Jena I want to express my thanks for the opportunity to direct your attention to one of the most interesting places in Thuringia and Germany. It is a pleasure for me to speak to you. You have been coming from all over the world to stay here in our beautiful city for the International Symposium „New Challenges in Earth Dynamics“. We, the citizens of Jena, appreciate that very much.

We are very happy that after Mizusawa/Japan, and Ottawa/Canada, Jena is the place where the „International Symposium on Earth Tides“ takes place. You are getting together here to discuss about the newest developments in Earth tides, crustal deformation, geophysical fluids and many other important and interesting matters.

Jena is a city, though a small one. A friend from Switzerland described it as follows: *"Jena is like Switzerland; you have everything in a small area."*

Jena is calling itself ***"city of light"***. The idea of light pervades everything that makes Jena extraordinary – from the bright figures of German intellectual history, like Schiller, Goethe, Hegel, Schelling or Humboldt, to the optical industry of the world-renowned companies of Carl ZEISS or Jenoptik; from latest research and innovations in the field of photonic technologies to the shining eyes of the children and of the Mayor when he is listening to people talking of our city.

In articles of the international press, Jena is not only called a *„boom town“* but also, and even more so, described as a model for the future. Why is that so? It’s because all growth factors significant for a modern European community are developing at the same pace. Science shapes the City in nearly every respect. The Friedrich-Schiller-University celebrates its 450th anniversary this year. The university and the University of Applied Sciences as wells as the eight highly respected research institutes of Jena are working very closely with our science based economy. Last year the title „City of science 2008” was awarded to the City of Jena. Therefore, this year is filled by attractive events, all related to science and light, the medium of Jena.

The soundness of a city’s development can best be judged by the so-called „soft“ location factors, which are of vital importance. All together there are about 25.000 students in Jena. 50 percent of all residents of Jena are less than 40 years old. This makes Jena the youngest City of Germany. In the state of Thuringia it ranks first with regard to children’s day-care facilities as well as to the high share of employees with an academic degree, which is 23 percent.

Together with Weimar, our nearby sister town which was Europe’s Culture Capital in 1999, Jena offers a rich variety of top-standard **cultural facilities and events** for all age brackets. Jena’s high quality of life is greatly appreciated by its residents and its guests alike. Let me quote from the weekly „The Economist“ of 22 February 2006, which said, *„In some ways, the city seems a double of Berkeley, California, complete with well-wooded hills dotted with professors' villas.“* (Berkeley is one of Jena’s twin cities, by the way.)

Jena is part of Germany’ east, which has become a member of the new Europe thanks to a revolution without bloodshed. What makes Jena outstanding is that it is an **encouraging example**. It serves as a model for other small cities in Europe, demonstrating its chances of development to them. The future-oriented scientific, industrial and administrative structures in our city are considered best practice examples even beyond Germany.

I invite you to enjoy our interesting city and to take a walk in the beautiful countryside around. I know there's not much time in between the oral presentations, but maybe you will manage to take some time off. Make yourself feel at home in Jena and enjoy your stay! We are happy that you are our guests!

Thank you very much for your attention.

Albrecht Schröter

Prof. Dr. Gerhard Jentzsch
President of Sub-Commission 3.1 on Earth Rotation and Earth Tides

Dear colleagues, ladies and gentlemen,

It is my great pleasure to warmly welcome you - also in the names of my co-organisers - to the Symposium on **New Challenges in Earth's Dynamics**, ***including the 16th International Symposium on Earth Tides***, which is a joint meeting of the sub-commissions of IAG commission 3 on **Geodynamics and Earth Rotation**, and the Inter-Commission Project 3.1 (GGP).

At the end of the last symposium in Ottawa, 2004, we decided to invite the other two sub-commissions and the inter-commission project GGP to prepare a joint symposium. I thank the presidents of sub-commissions

3.2	**Tectonic Deformation**:	Markku Poutanen
3.3	**Geophysical Fluids**:	Aleksander Brzezinski

as well as

IC-P3.1: **GGP Global Geodynamics Project:**	David Crossley

for their cooperation.

Actually, IAG-Commission 3 has now a fourth sub-commission (3.4) on **Cryospheric Change and Earth Deformation**, but this new sub-commission was not yet installed four years ago.

With my group I have the honour to host this symposium. I hope that you will get the feeling that we meet in an interesting city and in an attractive meeting place. After the first five symposia in Brussels (starting in 1954), Strasbourg 1969, Sopron 1973, Bonn 1977, Madrid 1985, Helsinki 1989, a second time in Brussels 1993, we meet again in Europe, and the second time in Germany.

In the name of my co-hosts I warmly welcome you to this symposium and wish you a pleasant and interesting week. In all, we are **114 participants from 24 countries!**

Considering that only about a third of the papers presented four years ago was strongly related to Earth and ocean tides, but to non-tidal signals and processes, like tectonic deformation or effects of fluids, the last symposium recommended to organise a joint symposium with the other two sub-commissions and the inter-commission project GGP, all active just in these fields.

During the past IAG-General Assembly in Perugia a new president of Commission 3 was nominated: **Mike Bevis** replaced **Veronique Dehant**. I was asked to continue to chair **Sub-Commission 3.1 Earth Rotation and Earth Tides,** and I asked **Spiros Pagiatakis** to continue as Vice-President. Following the recommendation of our former secretary **Olivier Francis**, who claimed that there was not much to do, we decided to run the sub-commission without nominating a new secretary. Nevertheless, I thank Olivier for his co-operation.

In cooperation with the existing sub-commissions Mike up-dated the terms of reference and introduced a new sub-commission 3.4. I sum up the terms of reference in short:

Sub-commission 3.1 addresses the entire range of earth rotation phenomena including tidal deformation, both on the experimental as well as on the theoretical level. In addition to tides, the task was augmented by variations in Earth orientation and rotation parameters, thus all the responsible phenomena like the full range of periodic and non-periodic phenomena including atmospheric dynamics as well as plate tectonics and intraplate deformation, and tidal friction.

Sub-Commission 3.2: Tectonic Deformation (President: Markku Poutanen / Finland, and VC Jeffrey Freymueller / USA), addresses geodetic signals that can be observed and are representative of the deformation mechanisms of the Earth's crust at different spatial and temporal scales. This includes the entire range of tectonic phenomena including plate tectonics, intraplate deformation, earthquake deformation cycle, aseismic phenomena such as episodic tremor and slip, and volcanic deformation. Like for sub-commission 3.1, the time scales range from seconds to years and from millimeters to continental dimension for the spatial scales.

Sub-Commission 3.3: Geophysical Fluids (President: Aleksander Brzezinski / Poland, VC: Mike Thomas), addresses mass transport in the atmosphere-ocean-cryosphere-mantle-core system, or the 'global geophysical fluids', that cause observable geodynamic effects on broad time scales. Although relatively small, these global geodynamic effects have been measured by space geodetic techniques to increasing, unprecedented accuracy, opening up important new avenues of research that will lead to a better understanding of global mass transport processes and of the Earth’s dynamic response. Angular momenta and the related torques, gravitational field coefficients, and geocenter shift for all geophysical fluids are the relevant quantities. They are studied theoretically and are observed using global-scale measurements and/or products from state-of-the- art models, some of which assimilate such measurements.

IC-P3.1: GGP Global Geodynamics Project (Chair: David Crossley)

This project was started to monitor changes in the Earth's gravity field at periods of seconds and longer, using the outstanding properties of the superconducting gravimeter. The GGP is named to indicate the application of gravity data to the solution of a number of geodynamic problems; also here, tides are still interesting, but rather as a signal to monitor the stability of the experiment than to find new features in tidal results. GGP data may define a reference for satellite data as well as for considerations concerning global mass changes and other geodynamic data. It relies on the IERS (International Earth Rotation and Reference System Services) as well as on ICET (International Center of Earth Tides).

The International Center for Earth Tides **celebrates its 50th anniversary this year**. From 1958 on it was situated at the Royal Observatory of Brussels, Belgium. It was one of the international data centers. But together with the retirement of the last director, Bernard Ducarme, it was decided **not** continue there . . . . Therefore, during the past four years one important task of sub-commission 3.1 was to find a new host for the Center: We asked different institutions (the names I do not want to mention here), but all potential candidates refused. Finally, two applications arrived, one from the **European Center for Geodynamics and Seismology**, Luxembourg, the other from a very special place … and last year in Perugia we decided to move the center to this very remote place: **Tahiti!** We are happy to have **Jean-Pierre Barriot** here! He will give a report during this symposium with his experiences about the move to the new place, the start of his work and about his intended activities. I should point out that Bernard Ducarme as the previous director is still supporting new ICET; **thank you, Bernard!**

We have to deplore the loss of valuable colleagues who passed away during the past four years. Only a couple of weeks after the last symposium in Ottawa had closed, **Paul Melchior** past away after a longer illness (05.09.1924 – 15.09.2004). He promoted Earth Tides, and he opened the world for Earth Tides research by arranging gravity tidal measurements all over the globe. He started as an astronomer observing the movements of the Earth’s rotation axis. From 1958 until 1995 he was director of the International Center for Earth Tides which he created; from 1984 until 1990 he was director of the Royal Observatory of Belgium. Under his guidance and later on, the observatory in Brussels was always a hospitable place for scientists from all over the world providing excellent working conditions. **Angel Venedikov** was one of those to benefit from these conditions; in 1966 he developed at the observatory a new computer program for tidal analysis which later became the standard analysis software at the observatory. Missing such working conditions at home in Sofia / Bulgaria, he took every chance to leave his home country. Beside Brussels, he also worked at places like Madrid / Spain, Kiel / Germany (1989), China (1987), Japan (1991). In Potsdam (1996), he developed another important orientation of his work: the study of anomalies in the records i.e. non-tidal signals, some of which can appear to be earthquake and volcano precursors. He died in December last year (05.07.1936 – 01.12.2007**).**

Johnny Flick was an outstanding and a remarkable person. He was firmly rooted in his native country, but he thought and engaged himself in international frames – like many great citizens of Luxemburg in the recent European history. Based on his persistence and flexibility (and humour) and his indefatigable engagements, Luxembourg could more and more become a centre for European geo-scientific communication and research, finally leading to the foundation of the *European Centre for Geodynamics and Seismology* (ECGS) with the *Musée national d'histoire naturelle* of Luxembourg as its legal seat. Johnny Flick became the first president of this new scientific centre. He died just recently (04.05.1930 – 10.04.2008).

To my knowledge came these three names. I ask you to rise and to keep one minute silence in their memory.

Thank you.
Gerhard Jentzsch

Award Ceremony.

This time, the Earth Tide Commission Medal was split and is given to two well known colleagues:

Bernard Ducarme and Tadahiro Sato

The documents as well as the nominating essays written by Walter Zürn for Tadahiro Sato and David Crossley for Bernard Ducarme are published in this volume of the Bulletin d’Information Marees Terrestres.

Citation for the Earth Tides Medal 2008
Bernard Ducarme

Less than a year ago I was happy to give an appreciation of Bernard Ducarme on the occasion of his retirement, at the end of 2007, from the Royal Observatory of Brussels, and from the Directorship of ICET, a position he had held since 1996. The ROB responded by devoting an entire special issue of the Bulletin d'Information des Marées Terrestres (BIM 007 – not generally available) in tribute, largely from his colleagues and co-workers who are, after all, the true judges of a person's worth.

In that issue, Bernard received many accolades, from: Ronald Van der Linden (Director General of the ROB), Jean-Pierre Barriot (U. French Polynesia), J. Barthélemy, Nicoleta Cadicheanu (Inst. de Geodynamique de l'Academie Roumaine), Rosa Mairana, Chueca, Veronique Dehant, Paul Paqet, Louisa de Ost, Jean Flick (Luxembourg), Cheng-li Huang (Shanghai Astronomical Observatory), Stefano and Vanda Panepinto (Sicily), Silvia Helena Soares Schwab (Brasil), Leslie Vandercoilden, Angel Venedikov, and others.

Bernard was cited for his intense and productive activity with ICET, for his energetic and diplomatic interactions with the world-wide community of geodesists, his generous time devoted to receiving visitors at the ROB, for the rigor with which he approached his work, for his humanity, his understanding of people's needs, and his availability. In addition he was known as a reliable expert in all matters to do with tidal theory and observation, from the smallest detail to the important papers such as tidal gravimetric factors. Many individuals praised Bernd's high intelligence and scientific rigor, combined with his strong personality that was for many years devoted to the service of his mentor Paul Melchior.

In addition to ICET, Bernard was Secretary of the CNBGG (Comité National Belge de Géodesie et Géophysique), a role in which his effort could have garnered the title of President as well. He was, like many scientists at ROB, associated with l'Université Catholique de Louvain, where he gained his academic credentials in the 1960's that would lead to a brilliant career spanning equally the two worlds of theory and observation in gravimetry. From 1969 he also enjoyed a close association with the ECGS (laboratory of geodynamics and seismology, Conseil de l'Europe) in Walferdange and became its Secretary. Johnny Flick speaks highly of his contribution to the ECGS.

Bernard had strong relationships with many countries, none more so than China. We tend to forget that he was responsible for processing the data from about 127 worldwide tidal instruments before the advent of the SGs. He has helped numerous scientists and students from the Wuhan Institute of Geophysics and Geodesy, the Wuhan Institute of Seismology, and others) both at ROB and at their home laboratories, and in field work (not to be forgotten in this era of Internet data!). It was particularly striking in these tributes how many times Bernard was praised for his competence, humor and understanding of the difficulties of others, and his patient explanations of problems. People who visited ICET always said they felt right at home in his presence.

Perhaps no one appreciated Bernard in the same way as Leslie Vandercoilden, his assistant who labored mightily on the treatment of data. Her task was magnified after the initiation of GGP when the data stream that had been a trickle form the older instruments turned into a flood with the 1 second sampling of the SGs. Anyone who has patiently processed raw SG data for even a few hours, would appreciate the huge task that Bernard set his assistant for many years. Her remarks about Bernard are, to be brief, glowing. In the above, I have extracted much from this special issue, without apology, to show that his recognition by the Earth Tides community comes from many different directions, not just my own point of view.

It is fitting that the last regular hard-copy issue of BIM (#143) included no less than 5 papers co-authored by Bernard, the last being the final paper of the late Angel Venedikov. This productivity, activity, and collegiality have been the hallmark of Bernard's career in Earth Tides. Now that ICET has been re-constituted in far-flung Tahiti, Bernard can rest in the knowledge that he has paid his dues to the service of science. He can now enjoy the recognition of receiving the Earth Tides medal for 2008 from the wider community represented here at the 2008 Jena Symposium on Earth Tides.

Few people have played such a pivotal role as Bernard Ducarme in the history of Earth Tides research. One thinks of the late Paul Melchior and Hans-Georg Wenzel for their wide ranging influence over the development of the subject in quite different fields of expertise. Bernard Ducarme, on the other hand, had an equally effective career at ICET, though he did it perhaps more quietly (well, most of the time!).

I think we can all agree that Bernard is a man of great service and integrity, and a gentleman. His management of ICET has been consistently energetic and well-organized, and he has helped hundreds of scientists, students, and lay people in his positions within the Royal Observatory of Belgium. He has an enviable knowledge of every aspect of Earth tides, from field operations in numerous countries to the coding of complex computer programs and data operations. At every step of the way, his advice has been sound and well received, and as an ambassador for the science of gravimetry he has made an outstanding contribution to geophysics.

For all of us associated with gravimetry, life will not be the same without Bernard. Perhaps this is best exemplified by his presence at workshops and meetings. At conferences, he participates with great enthusiasm, and is always ready with a question or comment on most talks. If Bernard does not ask a question about your presentation, then clearly you should feel left out (not relieved!). He certainly shines at conferences where he is always ready to discuss any topic, and he has helped organize many successful ones himself. Between 1991 and 2000, he was instrumental in the production of Workshops on the Intercomparison of Absolute and Superconducting Gravimeters (SGs) in Walferdange, Luxembourg. Not only was he an organizer and the main host, but he also was one of the editors of the famous Blue Books (Cahiers du Centre Europeen de Geodynamique et de Seismologie) that contained the very valuable proceedings. Bernard also had primary responsibility for producing the Bulletin d'Information des Marees Terrestres (BIM), whose volumes contain many classic papers that have not been published in the more well-known journals. BIM also contains on-line the proceedings of several recent workshops in gravimetry.

In more recent years the SG community has become used to coming here to Jena, under the organization of Gerhard Jentzsch (who previously led many Workshops in Bonn). The ET Symposium we are enjoying this week reminds me of the highly successful ETS that was held in Brussels in 1997, with the organization of Bernard (and O. Francis). As I recall, the final Banquet for that event was one of the best meals we ever had at any conference, living up to the fine reputation of Belgian cuisine.

Using modern academic terminology, one of Bernard's great strengths has been his outreach activities to the community, especially to foreigners. Like his longtime colleague Melchior, Bernard especially enjoys the respect and company of international scientists. He has brought together many distinguished gravimetrists from Eastern Europe, Russia, South America, and especially China. In the last decade especially he has been helping many Chinese scientists eager to work in gravimetry and to publish papers. More than the sometimes frustrating use of the English language, these papers are a testament to the encouragement Bernard has given for less well-known scientists to be heard.

One should also say something about his long publication list, going back to before I knew him (or rather of him) in the 1980's. Apart from his many papers with Melchior, in which Bernard no doubt did much of the data processing and analysis, his productivity has continued to this day on topics that are dear to his heart. His long continued analysis of data from the GGP (Global Geodynamics Project) network, especially on tidal aspects, will now unfortunately come to an end. Without any doubt, Bernard is one of the few scientists to see the big picture, and to successfully use the various gravimetry databases to the maximum benefit. Likewise his long friendship with the indefatigable Angel Venedikov led to numerous publications on tidal computer programs that may also be the end of an era. Bernard also championed the ETERNA software of Hans-Georg Wenzel, though as everyone knows, George was perfectly capable of publishing extensively on the theory and practice of ETERNA himself! Even for those gravimetry experts wedded to other ways of doing things, one has enormous admiration for the energy and loyalty of Bernard to his colleagues.

And so I end with my own thanks to Bernard for all that he has done for ICET and GGP in helping us move forward in this ever more complex science. Bernard is leaving a legacy of which he can be proud. I could always count on Bernard to supply some important information on stations, files, or people, just by a simple email. In future we will look to the new ICET and Jean-Pierre Barriot in faraway Tahiti, but I will always have in mind Bernard who has always put the interests of his colleagues first.

His unselfish devotion to the science and people in gravimetry is fully deserving of the Earth Tides medal for 2008. We wish him a healthy and fulfilling retirement with his beloved family.

D. Crossley,
St. Louis, August 2008.

International Union of Geodesy and Geophysics
Commission 3:
Geodynamics and Earth Rotation
Sub-commission 3.1:
Earth Rotation and Earth Tides

The commission on Earth Rotation and Earth Tides of the International Association of Geodesy awards the Fourth

EARTH TIDES COMMISSION MEDAL

to

Professor Bernard Ducarme

for his outstanding contribution to Earth tides research, especially his great service and integrity heading the International Center of Earth Tides.
This presentation is made the 1st day of September, 2008, at the 16th International Symposium on Earth Tides in Jena, Germany.

Gerhard Jentzsch
President

Spiros Pagiatakis
Vice President

4th Earth Tide Commission Medal

to

Tadahiro Sato-san

I met Tadahiro Sato-san for the first time at the 11th Earth Tide symposium held at Hanasaari, Helsinki in 1989. Before the meeting I had some letter exchange with Chris Harrison on an excellent paper Sato and he had written in the Geophysical Journal International on the strain tides at Esashi and he recommended strongly that I should meet Tadahiro there. Of course, I had known his name from his publications prior to this meeting. Well, it turned out that Tadahiro and I were sitting next to each other on the bus to Lohja and Metsaehovi and had quite a bit of time to talk. We were both working on the Nearly Diurnal Free Wobble at the time, so this was one of the subjects. Since then there were many more meetings and exchanges. The most memorable personal (and scientific) encounter was a very rewarding extended weekend he, Trevor Baker and I spent together in the Black Forest after the 2002 GGP-meeting in Jena.

Tadahiro's research contributions span a wide range of subjects: in type from logistical and experimental work on instruments and stations through programming of extensive codes to the sophisticated analysis of data, in frequency from secular and multiannual signals through the diurnal tidal range to the free oscillations of the Earth and marine basins, and coseismic gravity changes, more than 6 orders of magnitude higher in frequency. One of his very first contributions was when Chris Harrison and he solved the problem of adding linearized electrostatic feedback to LaCoste-Romberg geodetic gravimeters. Their paper resulted in a flurry of activity in other labs in Belgium, Germany and elsewhere and very quickly the recording of tides with such gravimeters without feedback was looked at with suspicion. Another service to the international tidal community followed with the programming of the ocean loading code GOTIC, which was used by many people, including myself. Just to mention a few research subjects he has been deeply involved with afterwards: the first detection of the incessant free oscillations of the Earth in 1998, the first detection of coseismic gravity changes in Japan after the Tokachi-oki earthquake 2003, the study of the Nearly Diurnal Free Wobble using gravity and strain data, global and regional ocean loading studies at daily and annual periods, the gravity effect of the Chandler wobble, comparisons of absolute with superconducting gravimetry, the geographical amplitude variation of the breathing mode ${}_0S_0$ and the loading by the tsunami near Syowa after the great Sumatra quake 2004, ocean bottom pressure variations, local elastic effects on earth tide strains, and seismic core mode studies. He realized very early that publication in English is important for making ones work known by the international community and that fighting the review process of internationally renowned journals is very worthwhile because it benefits the quality of the papers highly. So he has published his work in journals such as SCIENCE, Journal of Geophysical Research, Geophysical Journal International, Geophysical Research Letters, to name the most important.

However, another important part of his contributions to the Earth Tide community concerns the establishment of several observation sites. He set up the Esashi Earth tide station near Mizusawa, Japan, in 1979 and was operating that station until his move to the gravity section in a new institute now called "National Astronomical Observatory of Japan" which was established in July 1989. Some of his research work is concerned with the gravity and strain observations from Esashi. A major endeavour of his was the installation of a superconducting gravimeter (SG) at the Japanese Antarctic research station Syowa on East Ongul Island. He spent the Antarctic winter 1992 at the station to tend to the SG, but due to circumstances beyond his control returned with a broken instrument and a lot of experience and new ideas. In the same summer he returned to Syowa with a new SG and installed that instrument which has been operating now for more than 15 years. Notably the first detection of the Earth's incessant free oscillations in the data from this instrument was reported by Nawa et al. (1998). He went on to install SGs at Mt. Stromlo observatory near Canberra and at the Ny-Alesund research station on Svalbard. In between he went out on ships to install ocean bottom pressure sensors. Recently he sent me the preprint of a paper describing work on Earth and Ocean Tides near Juneau in the Alaskan panhandle using gravimeters and GPS receivers.

The large spread in latitude from the Arctic to the Antarctic of the GGP stations is essentially due to his efforts, of course in international cooperation. I believe, that the participation of the Japanese stations in the GGP-network has much to do with his personality and energy. He is one of the most insightful and active scientists within the tidal community and GGP worldwide and a very fine representative of the renowned and successful Japanese group and of Japanese scientific culture in general. Scientific truth and integrity are held high by him and in the subjects he works on his insight is always profound. The energy and perseverance he showed especially in the context of the installation of SGs at Syowa Station are simply incredible. His participations and contributions at international scientific conferences and workshops are always very much appreciated by the community. On the side: he has a great sense of humour, which often shines through in his oral presentations and which I personally like very much.

If John Goodkind received the previous ETC medal for inventing and providing the SGs (together with GWR) then Tadahiro Sato-san is the one making the best use of them, from installing such instruments in challenging places from Arctic to Antarctic to performing outstanding research with the records to exploit their best.

I sincerely congratulate Tadahiro Sato-san to the reception of one of the two 4th medals of the Earth Tide Commission at the 16th International Symposium on Earth Tides and wish him the best for his future work. May he be able to continue his excellent work for many years to come.

Walter Zürn
Black Forest Observatory

International Union of Geodesy and Geophysics
Commission 3:
Geodynamics and Earth Rotation

Sub-commission 3.1:
Earth Rotation and Earth Tides

The commission on Earth Rotation and Earth Tides of the International Association of Geodesy awards the Fourth

EARTH TIDES COMMISSION MEDAL

to

Professor Tadahiro Sato

for his outstanding contribution to Earth tides research: From co-seismic gravity changes to long-period non-tidal signals, from the experiment to the interpretation of body and ocean tides.

This presentation is made the 1st day of September, 2008, at the 16th International Symposium on Earth Tides in Jena, Germany.

Gerhard Jentzsch
President

Spiros Pagiatakis
Vice President

IAG Subcommission 3.1 “Earth Rotation and Earth Tides“

President: Gerhard Jentzsch, University of Jena, Germany

Minutes of the meeting of the subcommission, September 3, 2008 in Jena

1. Welcome and agenda of the meeting

There are 18 colleagues present. The list of participants is in the files.

2. Report of the President

After the last meeting during the IUGG General Assembly in Perugia, 2007, (at that time still Earth Tide Commission) the main tasks comprised:

(1) the formulation of the terms of reference of comm.. 3 and subcomm. 3.1 together with Mike Bevis as the new president of comm. 3;

(2) the preparation of the 16. International Symposium on Earth Tides in the frame of a joint meeting of the three subcommissions of IAB commission 3;

(3) the advertisement for a new place for ICET and the preparation of the decision for UFP Tahiti;

(4) contributions to the preparation of the programme of the next IAG meeting in 2009.

3. Report of ICET

This report was given by Bernard Ducarme; the new ICET director Jean-Pierre Barriot arrived later. B. Ducarme will support new ICET in all aspects (software, archive, …).

The Bulletin (BIM) will be continued, but in electronic form. Only a few printed copies will be distributed to libraries and on special request.

4. Working groups

(1) **H. Schuh** reports about the WG 6, Solid Earth Tides in Space Geodetic Techniques. As the Vice-Chair he informs that the group was not very active during the past year. During the discussion Paolo Mendes volunteers to chair the group. He is accepted by the audience by acclamation.

(2) WG 8 on Gravitational Physics, chaired by **L. Manshinha**, was not active. It is decided to stop this WG.

(3) WG on Precise Tidal Prediction: **Y. Tamura** reports about starting activities concerning the comparison of computer programs. He prepares a homepage of the WG. He intends to distribute software regarding data analysis and loading prediction.

(4) Study Group on Environmental Effects in Tidal Records chaired by **C. Kroner:** This group was very active organizing a joint meeting together with GGP in Jena in 2006. The main goal is to provide 3D reductions of environmental effects. A comprehensive report will be published in BIM.

(5) The intercommission WG on Absolute Gravity, chaired by **H. Wilmes**, is adopted by our subcommission, because such measurements play an important role especially for GGP.

4. Name of Subcommission 3.1:

The name of our subcommission was formulated by Mike Bevis. As it looks like, we are not much involved in Earth Rotation. Therefore the recommendation is accepted to change the name of the subcommission to **Earth Tides** only.

5. Earth Tide Commission Medal

Taking into account that the organization to IAG and commission 3 has changed names, and considering that medals are mostly named after a scientist especially successful in this field, we decided to rename the medal to **Paul-Melchior-Medal**.

6. Next meeting

Our commission accepts with great pleasure the invitation of the National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, to hold the next symposium in Egypt. Like in this meeting, the other subcommissions of comm.. 3 as well as inter-commission study groups should be invited to take part.

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Resolutions - ETS 2008

1. **Realizing** that the scope of subcommission 3.1 does not cover Earth Rotation, and **considering** that this topic was not supported by special sessions during the Symposium 2008 in Jena, ETS2008 **recommends** renaming subcommission 3.1 to

   Earth Tides

   only.

2. **Realizing** that the name of the Earth Tides Commission changed to subcommission 3.1, and **recognizing** the contribution of late Prof. Paul Melchior to Earth Tides, ETS2008 **recommends** renaming the Earth Tides Commission Medal to

   Paul Melchior Medal

3. **Considering** that Earth Tide phenomena are included in all fields of Geodynamics, and **recognizing** the success of including subcommissions 3.2 and 3.3 in the preparation of this Symposium, ETS2008 **recommends** inviting all subcommissions of Comm. 3 (including intercommission committees) to the next symposium. The title of this symposium should reflect the new developments.

4. **Noting** that ocean tide models often consist of estimates of the tide height only, and **recognizing** that the angular momentum of both, tidal currents and tide heights are needed to model tidal effects, ETS2008, **recommends** that ocean tide models provide estimates of both, barotropic tidal currents and tide heights.

5. **Noting** that GGP is an integral component of the IAG GGOS program, and relies on the successful operation of the GFZ/ISDC database in Potsdam for the exchange of SG data, and **recognising** that GFZ Potsdam has an ongoing contract to provide services to the International Center of Earth Tides, ETS2008 **recommends** that the President of the Earth Tides Sub-Commission convey in writing to GFZ that difficulties with the funding of the GGP/ISDS database need to be resolved with some urgency to permit the GGP database to operate without interruption.

6. **Noting** that remarks have been expressed at this ETS2008 Symposium concerning the possible transition of the GGP from an Inter-Commission project to an IAG Service, ETS2008 **recommends** that GGP and ICET engage in further discussion of the full implications of this suggestion, with a view to resolving the question for a decision on this issue at the 2011 General Assembly of the IUGG.

7. **Noting** that a new management of ICET has, since 1 January 2008, undertaken the task of running the GGP database from the University of French Polynesia and **recognising** the sincere appreciation of the GGP community to J.-P. Barriot, the new ICET Director, for assuming this responsibility, ETS2008 **recommends**

that ICET perform the following tasks for the benefit of the GGP database and community of users:

(a) standardize the structure of the GGP 1-minute files for all existing and future data,
(b) provide a calibration history of each SG in the GGP network, that will be accessible to all users,
(c) provide verification to the data provider that files have been received in readable format consistent with GGP standards, and
(d) implement a procedure for providing corrected 1-minute data and the results of tidal analysis of such data, to all users of the GGP database.

8. The conference accepts with great pleasure the invitation of Prof. M.M. Salah of the **National Research Institute for Astronomy and Geophysics (NRIAG), Helwan / Cairo**, to hold the next conference in Egypt in 2012.

9. On behalf of all participants at the Symposium on New Challenges in Earth's Dynamics including the 16th International Symposium on Earth Tides, IAG Commission 3 and the Global Geodynamics Project thank Friedrich-Schiller University and all sponsors of the symposium for their generous support and contributions that played an important role in the success of the symposium. The ETS2008 participants thank the Local Organising Committee, Gerhard Jentzsch (Head of LOC), Thomas Jahr, Corinna Kroner, Eva-Maria Weder, and Janet Kreßler for their warm welcome and flawless organisation that made the Symposium a great scientific success.

Report

of the

Special Study Group

on

‚Analysis of Environmental Data for the Interpretation of Gravity Measurements‘

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The special study group, in which the influence of the environment on terrestrial geodynamic observations is investigated, is still quite in demand. Since the last report in 2004 a clear tendency towards studies on hydrological influences is found, not only with respect to their reduction in data sets, but also with regard to their utilization for hydrology or hydrogeology.

March 27 - 31, 2006 a workshop was held in Jena shared with a workshop related to the ‘Global Geodynamics Project’. In all 40 scientists from 17 countries attended. Papers presented during the workshop were published in the Bulletin d’Informations des Marées Terrestres, vol. 141 - 143, by the International Center for Earth Tides. The consideration of environmental influences in geodynamic observations was also topic of a several presentations and discussions during the meeting on ‘New Challenges in Earth’s Dynamics’ in Jena in 2008. At the business meeting of the conference a report of study group activities was given. It is planned to have another workshop in 2010, probably in Potsdam.

Essential results comprise

- For studies related to long-period signals an atmospheric reduction based on 3D meteorological data is required. The zone that ought to be considered extends to a distance of about 5-6°. Atmospheric mass shifts above the rest of the earth’s surface can be taken into account according to Merriam (1992) using surface data and a standard atmosphere, but they should not be neglected.

- Problems exist with regard to the general accessibility of the meteorological data. The temporal resolution of 4 values per day is not enough to provide appropriate reductions for studies on short-term phenomena. A certain improvement is obtained when introducing higher-resolved barometric pressure data monitored at the station into the computation of the 3D reduction (Klügel & Wziontek, 2008).

- A first comparison of 3D reductions based on different meteorological data sets and programs was done (cf. Klügel & Wziontek, 2008). No principal systematic deviations were found. In the range of a few days differences of several nm/s² can occur. It was shown again that for an appropriate reduction an elevation of at least up to 50 km needs to be considered.

- To improve signal-to-noise ratios in the data sets the necessity might exist to consider special meteorological phenomena i.e. related to particular pressure events (i.e. Nov. 2004) or storm surges.

- Investigations carried out during the last years underline the importance of removing hydrological influences in the data prior to geodynamic studies. To fulfil this requirement there is almost always the need to improve the understanding of local hydrological conditions. In particular for gravity a monitoring of soil moisture variations is beneficial. Currently these observations are not done at many observatories.

- From first comparisons SG data, satellite-derived temporal gravity field variations, and gravity effects based on global hydrological models a principle good agreement is found. A consistent treatment of the data sets is essential in these studies. Likewise a consideration of local hydrological influences is necessary.

- It is recommended to strive for a more intensive cooperation between AG and SG groups as well as for a combination of data with GPS for studies of long-term effects

- It can be reported that during the last years there were several successful applications of tilt- and strainmeter data sets to geodynamic investigations despite the sensitivity of these observations to environmental variations.

Klügel, Th., Wziontek, H., 2008. Correcting gravimeters and tiltmeters for atmospheric attraction. ETS2008 – New challenges in earth's dynamics, Jena, Sept. 2008.

Merriam, J., 1992. Atmospheric pressure and gravity. Geophys. J. Int., 109, 488 - 500.

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In memoriam.

Am 10. April 2008 ist Johnny Flick im Alter von 78 Jahren verstorben. Im engsten Familienkreise wurde er am 15. April auf dem Nikolaus-Friedhof von Limpertsberg (Stadt Luxemburg) beigesetzt. Eine anschließende feierliche Messe in der Kirche zu Merl mit einer großen Anzahl von Trauergästen war seinem ehrenvollen Abschied gewidmet.

Mir sinn an déiwer Trauer fir eise gudde Frënn Johnny Flick!

In his speeches Johnny Flick liked it very much to express his messages consecutively in different languages. That's why this form of communication shall be applied here as well - as a special reference to his European identity.

Johnny Flick was an outstanding and a remarkable personage. He was firmly rooted in his native country and coincidently thinking and engaging himself in international frames – like many great Luxemburgers in the recent European history. This feature of his personality together with his persistence and flexibility (and humour) when willing to reach a goal is the key to understand why, owing to his indefatigable engagements, Luxembourg could more and more become a centre for European geo-scientific communication and research, finally leading to the foundation of the *European Centre for Geodynamics and Seismology* (ECGS) with the *Musée national d'histoire naturelle* of Luxembourg as its legal seat. Johnny Flick became the first president of this new scientific centre. And when recently the University of Luxembourg was founded, he felt it as one of his great fortunes that he could live to see what he regarded as a historical event for his country.

Johnny Flick got his geodetic education at the University of Karlsruhe (Germany).
Er schloß sein Studium mit dem Grad eines Diplomingenieurs für Geodäsie und Vermessungswesen ab. Zeitlebens verband ihn eine besonders innige Beziehung zu seiner Alma Mater und seinen dortigen Kollegen, insbesondere mit seinem akademischen Lehrer Prof. Lichte, der ihm ein Freund und Ratgeber war. Dies verdient deswegen eine besondere Hervorhebung, weil Johnny gleichzeitig nämlich ein Gesangsstudium als Tenor aufgenommen hatte und lange Zeit nicht so genau wußte, welchen Beruf er denn schließlich ausüben sollte. Wir alle, die wir Johnny so lange kannten, erinnern uns mit Bewunderung an seine glockenklare Tenorstimme. Auf den Rat seines väterlichen Freundes hin entschloß er sich dann zunächst für den Ingenieur als Hauptberuf. Ihm gelang es dann später in erstaunlicher Weise seine Tätigkeit als Ingenieur und Künstler miteinander zu verbinden.

Johnny Flicks späteres Wirken auch in der Wissenschaft war immer geprägt durch eine Verbindung von rationalem Ingenieursdenken und Kunst. Wissenschaft war für ihn primär ein Ausdruck menschlicher Kultur, der die moderne technokratische und anwendungsorientierte Nutzung lediglich beigeordnet war. In gewisser Weise betrachtete er Wissenschaft als eine Form der intellektuellen und experimentellen Kunst.

Aujourd'hui, le Centre Européen de Géodynamique et Séismologie, les Journées Luxembourgeoise de Géodynamique, le Laboratoire Souterrain de Walferdange sont bien connus et bien établis dans les réseaux des activités géoscientifiques internationales. Mais le chemin vers l'état présent était long et pénible. L'histoire des *Sciences de la Terre au Luxembourg* est décrite dans le livre du même nom, édité en 2002 par J. Flick et N. Stomp (ISBN 2-919877-00-8), une documentation vraiment impressionnante, de plusieurs points de vue. Laissons Johnny, dans ce livre, encore une fois raconter comment tout a commencé:

Quelques moments inoubliables des nombreuses années de collaboration belgo-luxembourgeoise et internationale.

Jean A. Flick

Un peu d'histoire
1 - Prologue:
Casemate du St. Esprit

Au début de l'année 1963, l'attaché ministériel N. Weber m'annonce qu'il sera au rendez-vous du mardi soir à mon club de jeu de quilles. Pendant la partie, il me parle d'une correspondance datant de 1962 entre l'Observatoire Royal de Belgique (P. Melchior) et le Ministère des Arts et des Sciences (Ministre P. Grégoire) concernant la possibilité d'installer un gravimètre à Luxembourg. M. Weber souhaitant éclaircir quelques points, me posa différentes questions: «Peux-tu manipuler un gravimètre, ou as-tu néanmoins vu ou touché un appareil de ce genre?» J'ai affirmé l'avoir vu à l'Institut de Géodésie de l'Université de Karlsruhe où j'ai étudié sa théorie, son fonctionnement et appris qu'il existe différents types de gravimètres. N. Weber m'informe alors que le ministre a décidé de permettre à l'Observatoire Royal de Belgique de faire fonctionner un gravimètre Askania avec son enregistreur dans une salle de la casemate du Saint Esprit (suivant les instructions de M. J.P. Koltz, historien) pour une période de 6 mois. Il m'annonce également que le Ministre recherche un volontaire pour la maintenance journalière nécessaire et souhaite me proposer. Le rendez-vous inaugural est fixé au 12 mars 1963.

Le jour "D" à 14 heures un groupe de quatre personnes se réunit devant l'entrée vers la casemate « ënnert dem Kanounenhiwel » Une descente de 145 marches nous attendait, illuminée faiblement par des lampes électriques le long d'un câble fixé latéralement à la galerie: Au tournant à gauche, se présentaient trois salles consécutives, reliées entre elles par 6 à7 marches. Dans la première un socle en béton a été coulé sur lequel le gravimètre Askania trônait en phase d'échauffement. Les quatre personnes réunies devant ce bel instrument plein de secrets étaient: les professeurs Paul Melchior de Bruxelles et Albert Gloden de Luxembourg, l'attaché N. Weber et moi-même. L'air était humide et on y respirait la roche moisie. M. Melchior donna les premières informations. Pour moi l'aventure inattendue venait de commencer.

Fig. 1: Station Gravimétrique aux Casemates du St Esprit (1963-1971)

À cette époque – qui marque aussi le temps pionnier des recherches de marrées terrestres – a commencé la coopération et la profonde amitié entre Johnny Flick et Paul Melchior, Chef de Département et plus tard Directeur de l'Observatoire Royal de Belgique.

Au cours du temps, les activités expérimentales se sont développées aussi bien que la puissance des instruments d'observation géodynamique. Finalement, il fallut constater que le bruit de fond dans la région de la ville de Luxembourg était trop important. Ainsi, les scientifiques ont été obligés de chercher un autre lieu, spécialement eu égard à la nécessité scientifique d'effectuer aussi des mesures inclinometriques, extensometriques et séismiques de haute résolution. Nous en venons donc à la fondation du Laboratoire Souterrain de Walferdange et laissons de nouveau Johnny Flick raconter:

6 - La découverte des galeries de gypse

Jean A. Flick

La découverte des galeries de gypsese situe vers la fin de l'année 1967. En février 1968 le site a été soumis au test du pendule horizontal en quartz; le développement des papiers photosensibles a révélé un enregistrement parfait, un grand pas en avant dans l'étude de la marée terrestre à Luxembourg et une grande satisfaction de plus pour les créateurs de l'instrument Verbaandert/Melchior. Effectivement ce premier enregistrement obtenu après quelques mois d'expérimentation des pendules horizontaux, la qualité des ondes de marée a égalé celle de Sclaigneaux en Belgique datant de 1959. On aurait pu dire que la planète Terre a parfaitement réussi à fournir la partie graphique de son "cardiogramme" sous l'influence des variations de la pesanteur (jeux d'attraction entre Terre/Lune/Soleil). Les voiles de notre jeune vaisseau scientifique étaient gonflées et faisaient oublier très vite la crainte de devoir abandonner notre aventure en géophysique. Paul Melchior promit de faire un bond de joie à la sortie de la mine... sans risquer de se coincer la tête.

Aussi, à l'Université de Karlsruhe, le directeur de l'Institut de Géodésie, le professeur H. Lichte et son adjoint le Dr H. Mälzer, n'hésitaient plus à rendre visite à cette nouvelle trouvaille à Luxembourg et de voir les installations de J. Flick, leur ancien étudiant en géodésie, enthousiasmé et soutenu à merveille par le professeur P. Melchior de Bruxelles. H. Lichte donnait raison à P. Melchior en disant à son départ: „Hier erwarten Sie noch ungeahnte Möglichkeiten in einem 90 m tiefen, trockenen, abgelegenem Stollen, kilometerlang..." Sa vue était claire comme la nôtre. (Nov. 1968)

Le Laboratoire de Géodynamique (géodésie et géophysique) et de Séismologie dans une ancienne mine de gypse à Walferdange (Helmsange)

Salle des clinomètres – VM-VMR (B) à gauche en essai: pendule espagnol et clinomètre français

Au début, les galeries de la mine de gypse à Walferdange étaient un désert souterrain, en quelques lieux «un peu» dangereux compte tenu du fait qu'à cette époque des explosifs étaient encore utilisés dans le cadre de l'exploitation du gypse. Finalement et comme première étape, « on », c'est-à-dire surtout Johnny, a réussi à préparer une partie du système étendu des galeries comme salle d'observation – par ses propres mains (!) - et rapidement il devient évident que la mine convenait idéalement pour effectuer les mesures géodynamiques de haute résolution métrologique envisagées. Temporairement, à coté de ses devoirs professionnels, Johnny Flick dévouait pratiquement tout son « temps libre » à la construction et au développement de la mine de Walferdange comme observatoire géo-scientifique et laboratoire expérimental, prévu pour être mis à la disposition libre de la communauté internationale de chercheurs. Et pendant de très nombreuses années, Jonny Flick portait la charge deaintenance des nombreux instruments installés dans la mine, ceci avec une grande compétence multidisciplinaire.

It was in 1969 that Paul Melchior and Johnny Flick had the idea to organise regularly international conferences on geodynamics at Luxembourg, complementarily to the growing experimental research. One has to know that in those days the quantity of international scientific meetings was still rather limited. However, the basic problem for the realisation of the idea was not a scientific but practical one, namely how to organise and realise such meetings locally, mainly to find an appropriate venue, where all participants could gather for minimum expenses and where conferences, overnight stay and boarding took place under the same roof, as a basic condition that after the conferences all participants could remain together and could get in friendly and unconstrained contact with each other for discussions and exchange of opinions. It took some time, but finally Johnny Flick, with the engaged support of many Luxembourg personages and authorities, succeeded to find a solution which was a venue near to the city of Luxembourg at the *Institut Pédagogique* in Walferdange, a former *caserne militaire*.

The meetings were named *Journées Luxembourgeoises de Géodynamique* and the first one took place in the early seventies; Paul Melchior was the first president. In autumn of last year the 94th JLG were hold, an impressive example for the vitality of an excellent idea. From the beginning and until now the conception and objectives of the JLG were and are interdisciplinary communication in context with the intention to get mainly young scientists familiar with interdisciplinary thinking, complementary to strongly specialised research in modern time. During the first years earthtides and their fundamental relation to other disciplines played a special role, and as long as he could the Nestor of earthtide research Paul Melchior himself presented actual problems and modern results in his famous and matchless manner.

Successful and efficient interdisciplinary communication and co-operation is tied to fundamental *human* preconditions, which are: confidence to each other, friendly mutual respect and common scientific curiosity, out of which scientific inspiration may arise. It was Johnny Flick who implanted that spirit into the *Journées Luxembourgeoises de Géodynamique* – a spirit which got named the *spirit of Luxembourg*, a spirit which was personified by Johnny Flick himself.

Aside of his multifarious activities for the development of the «*Sciences de la Terre au Luxembourg*» Johnny Flick was scientist too and author or co-author of many scientific publications. He received many official signs of appreciation. But Johnny Flick was a very modest personage who did not like to stand too much in the focus of interest. Therefore I shall here relinquish the usual documentation and just mention representatively:
Ingénieur Directeur honoraire de la *Ville de Luxembourg*,
Président honoraire du *Centre Européen de Géodynamique et de Séismologie*,
Astronome correspondant de l'*Observatoire Royal de Belgique*.
And for not overlooking his live as artist:
Président d'honneur du *Madrigal de Luxembourg*, of which he was one of the foundation members.

What particularly meant to him so much were all these frequent friendly and personal communications with so many scientists worldwide, outlasting the times. As a matter of fact they were a sign of the unlimited human appreciation of Johnny Flick.

Johnny Flick has published - more or less regularly – many articles in the press of Luxembourg where he described in his vivid and understandable manner the substance of actual geo-scientific problems and their potential solutions (and the potential contribution of the *European Centre for Geodynamics and Seismology* as well!). By this means he achieved a remarkable anchoring of the "*Sciences de la Terre"* in the Luxembourg society, like hardly in any other country of the world. This gets remarkably visible by the fact that His Royal Highness the Grand Duke Henri has accepted to be *Président d'honneur du Centre Européen de Géodynamique et de Séismologie*!

Johnny Flick could develop his powerful creativity because he had that homey environment which he needed:
Als erstes ist hier zu nennen seine Familie, insbesondere seine Frau Betty, die ihm unermüdlich zur Seite stand und ihm den Rücken freihielt für seine vielfältigen Aktivitäten; so hat auch sie einen großen Anteil an Johnny Flicks erfolgreichem Schaffen. Es sind zu nennen seine unzähligen Luxemburger Freunde und Bekannte, die vielen Vereine und lokalen Institutionen unterschiedlichster Art, in denen er Mitglied war oder in denen er sich in anderer Form engagierte. Diese menschlichen Beziehungen zu seiner geliebten Heimat prägten seinen Lebensablauf und sein Denken. Es war immer wieder eindrucksvoll, mit Johnny Flick während des Tages über den großen Markt von Luxemburg zu gehen; man brauchte viel Geduld, denn immer wieder wurde er von Menschen angesprochen, und er nahm sich die Zeit, mit Ihnen über die unterschiedlichsten Dinge zu plaudern. Man könnte sagen, daß Johnny Flick schließlich selber zu einer Luxemburger Institution geworden war. Als Bestätigung ließe sich jener Brief anführen, dessen Adresse einfach lautete „Johnny Flick, Luxemburg" und der problemlos den Adressaten erreichte.

Johnny Flick's principles and convictions based on the ideas of humanism.
Er war ein Mann klassischer Bildung im Humboldtschen Sinne. Unvergeßlich sind mir unsere vielen Gespräche über philosophische Themen. Diese Gespräche führten immer wieder zu jener grundsätzlichen Frage: wie kann es sein, daß in einer Welt aus physikalischen Elementarteilchen etwas entstehen konnte, das wir Leben und individuelles Bewußtsein nennen. Erfordert doch selbst das Evolutionsprinzip letztlich eine initiierende Kraft. Johnny Flick, der Musiker, nannte diese Kraft immer den „großen Dirigenten". Dieser Dirigent hat Johnny Flick nun heimgeholt.

A very personal retrospective glance:
Es sind erst wenige Jahre vergangen seit jenem Abend, als Johnny Flick, Paul Melchior und ich nach einem Abendessen noch lange zusammensaßen, über Vergangenheit, Gegenwart und Zukunft des ECGS sprachen und Anekdoten aus der Geschichte des ECGS erzählten (deren gibt es viele!). Wir hatten noch gemeinsame Pläne und Ideen. Der Abend wurde zunehmend fröhlicher und Paul definierte uns schließlich als die „drei Musketiere von Luxemburg". Nach unerwartet kurzer Zeit bin ich nun der verbliebene Letzte dieser Musketiere, dem die Aufgabe zugefallen ist, diese Zeilen zu schreiben.

Ich möchte mit ganz einfachen Worten schließen:

Danke, Johnny!
Merci fir alles!
Johnny, mir wäerten dech net vergiessen!

Manfred Bonatz

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Integrating surface and space-based gravity observations in hydrologic studies
(Extended Abstract)

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1.0 Introduction

There are now multiple gravity measuring instruments capable of precision at the one microgal level or better. Of interest in this discussion are the Superconducting Gravimeter (SG) and the space-based Gravity Recovery and Climate Experiment (GRACE). Gravity variations at the microgal level include many effects of local and distant water mass redistribution (Llubes et al, 2004), and although traditionally viewed as a source of noise, there is increasing interest in using these variations to improve understanding of the hydrologic cycle. To have a significant impact, gravimetry must contribute tangibly to numerical data-assimilating Land Surface Models (LSMs), now the mainstay of the hydrologic sciences. Contributions may be made in (1) validation of LSM predictions, (2) calibration of individual elements of an LSM, (3) parameter estimation, and (4) direct assimilation, as a new data type in addition to more conventional data. Here we briefly review examples in which GRACE and SG observations contribute in these four ways.

Since the GRACE launch in 2002, LSM's were used to validate gravity field variations products at seasonal time scales. Figure 1 (from Syed et al 2008) is an example.

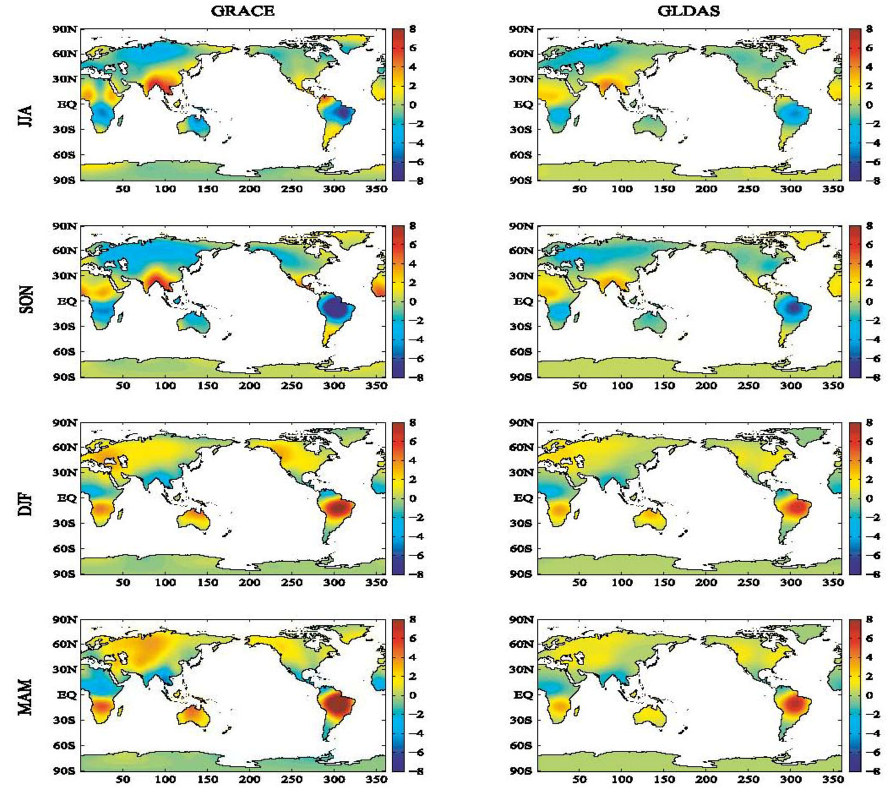
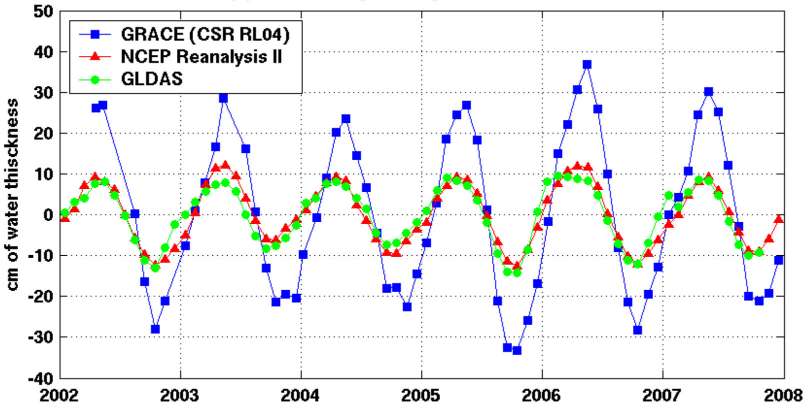


Figure 4. Spatial patterns of seasonally averaged TWSC (cm/month) from GRACE and GLDAS. On the basis of the seasonal averages computed for the period of April 2002 till July 2004.

Figure 1: A comparison between the GRACE gravity change expressed as surface mass change in centimeters of water, and calculations of water storage change from the Global Land Data Assimilation System (GLDAS) averaged for 3 month periods representing the 4 seasons.

LSM's continue to be used to validate and assess GRACE (Wahr et al, 2006), but there is now sufficient understanding that GRACE can be used to measure LSM performance. We illustrate this with an example from the Central Amazon, in Figure 2.


(a) Water Storage Change in Central Amazon

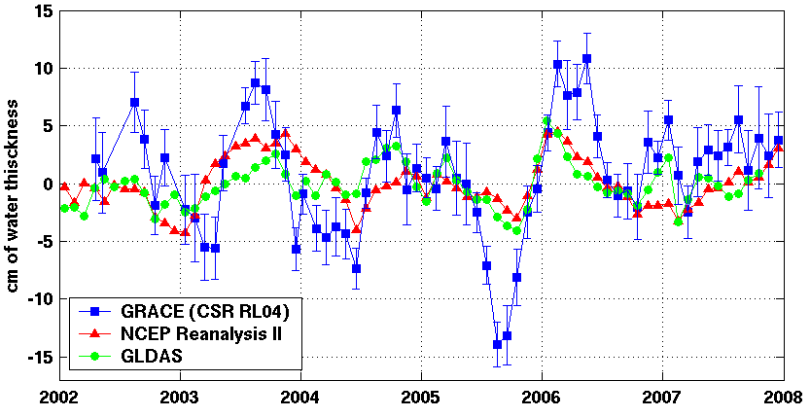

(b) Non-seasonal Water Storage Change in Central Amazon

Figure 2: Upper Panel: Time series of monthly water storage change in the Central Amazon estimated from GRACE (CSR RL04 data set), and two LSM's, GLDAS and the NCEP Reanalysis II. Both show dominantly seasonal variation, but GRACE amplitude is nearly double that of the LSM estimates. Lower Panel: After subtracting the best least square fit sinusoids of 1 and 2 cycles per year from each series. The strong negative anomaly near the last half of 2005 is largely absent in the LSM estimates. Error bars are estimated from rms variability over tropical oceans where signal should be near zero in GRACE.

Figure 2 shows significant differences between two LSM estimates and GRACE. An over estimate by GRACE seems unlikely because smoothing or truncation of high degree harmonics to suppress noise typically reduces variability (Chen et al, 2006). If the seasonal terms are removed from each series, (lower half of Figure 2) LSM estimates show little variability, compared with the large negative storage anomaly at the end of 2005 in the GRACE series. This was time of the worst drought in the Amazon in over a century (Rohter, 2005). GRACE thus provides a useful way to validate LSM performance, in this case showing that the two models are deficient in their ability to model unusual events such as drought. Further evaluation of GRACE may also show that the two LSMs underestimate seasonal variability.

2.0 GRACE Calibration of LSM Components

GRACE can be used to calibrate isolated elements of LSM's that may be omitted or are otherwise difficult to quantify. We consider two components, groundwater storage (GWS) and snow water equivalent (SWE). In-situ observations, GRACE data, and LSM estimates of water cycle components are combined to calibrate these components, starting with a simple water balance equation which includes precipitation P, runoff R, evapo-transpiration E, Soil Moisture Storage SMS, and SWE and GWS. An LSM typically assimilates observations of P, then estimates R, and E, and some Storage Change elements. The water balance equation is

$$\text{Storage Change} = P - R - E = SWE + SMS + GWS$$

GRACE measures all three components of Storage Change, but suppose a data assimilating LSM estimates SWE and SMS, but not GWS. Then it can be estimated by

$$GWS = \text{Storage Change (from GRACE)} - [SWE+SMS] \text{ (from LSM)}$$

Figure 3 from Rodell et al (2007) compares such an estimate of GWS with independent well data over the Mississippi basin. The good agreement shows that GRACE can provide useful information about the GWS part of the water cycle.

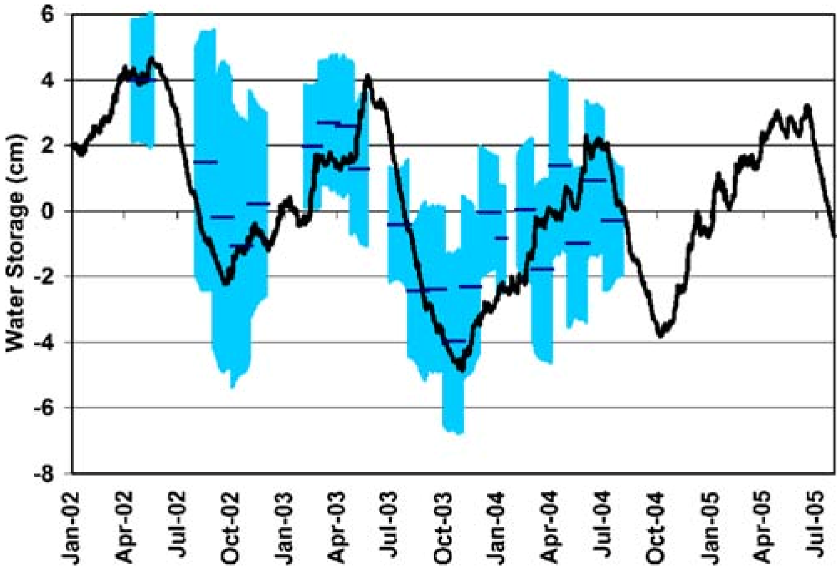


Figure 3 - Ground water storage change from the difference of GRACE and the LSM GLDAS, averaged over the Mississippi basin. The blue bars show approximate uncertainty about the GRACE estimate. Seasonal variations in the GRACE estimate are comparable to the estimate from well levels. This idea could be used world-wide, in areas where few wells are available.

In principle, any other component of the water cycle (P, E, GWS, SMS, SWE) can be calibrated in a similar way. For example SWE has been estimated by Niu et al (2007) as shown in Figure 4. At high latitudes in the Northern Hemisphere, the principal winter water storage is as SWE, though there is also SMS. Figure 4 compares SWE from microwave emissions (AMSR-E) with an estimate from GRACE minus an LSM estimate of below-ground storage (Here the LSM is CLM 2.0, the model of the US National Center for Atmospheric Research). The GRACE estimate agrees better in amplitude and spatial distribution, with in situ observations (climatology) (Figure 4d). Spatial resolution of GRACE is relatively poor, so Figure 4c is a smoothed CLM SMS estimate at the same resolution. Clearly gravimetry (GRACE) provides a useful calibration of SWE.

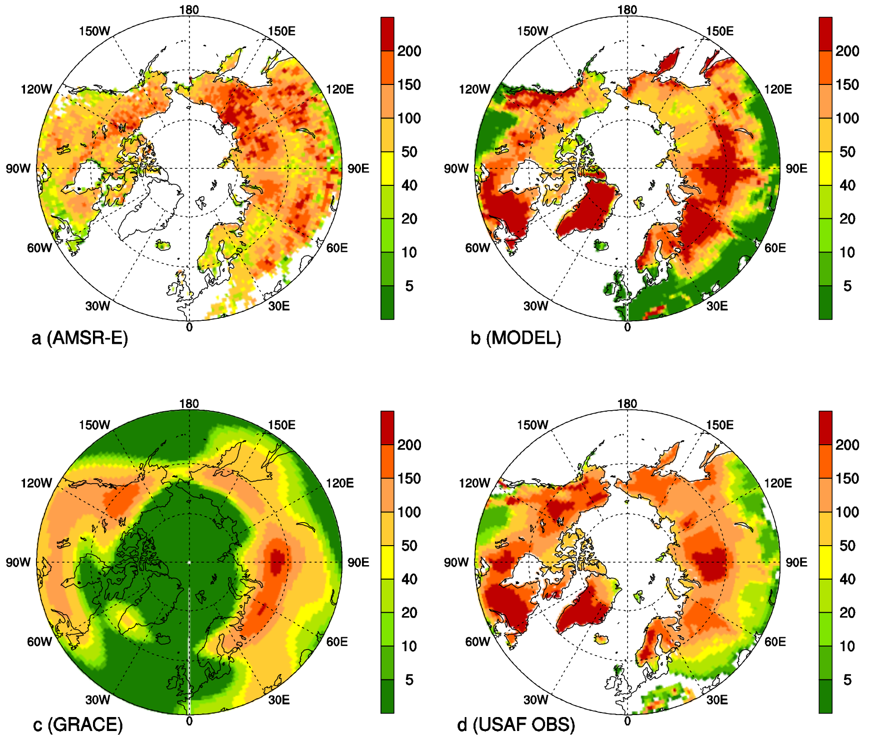


Figure 4 Snow water equivalent (mm) in March 2004. (a) AMSR-E, (b) GRACE RL04 TWS minus unfiltered (CLM) model of below ground water storage change, (c) As in (b) but with spatial filtering applied to CLM model of below ground storage, (d) USAF/ETAC ground-based climatology=snow depth x (300 kg /m^3). The combined GRACE / CLM model result agrees better with surface observations (d) than microwave estimate from AMSR-E. Microwave estimates are known to have limitations in boreal forests that dominate these regions.

3. SG Estimate of a Hydrologic Parameter

Specific yield is a parameter used to convert well level change to equivalent water storage change in an unconfined aquifer. The parameter is required in hydrologic models, and in resource management to quantify in-ground reserves. Many studies have demonstrated that the SG is capable of estimating specific yield (e.g. Takemoto et al 2002), by observing well level changes adjacent to an SG site. Therefore, to make the SG a useful hydrologic instrument, it should be transportable to locations of interest. We have adapted a conventional SG to this configuration, and are using it in Central Texas over the karst Edwards Aquifer, where there is an extensive well monitoring network, but no direct measurement of specific yield. The experiment is designed to test the feasibility of field operation of the SG, transportability with the sphere in a superconducting state, and value of the SG as a hydrologic instrument.

Figure 5 shows the configuration of the transportable SG. The dewar containing the SG sensor plus all electronics are housed within an aluminum box. A separate box of similar size contains the refrigerator to maintain liquid helium temperatures in the dewar, and a UPS (Uninterruptable Power Supply) for power backup. The two aluminum boxes are connected by refrigerator hoses and power cables, and housed in a shed for weather protection and climate control. The SG monument consists of steel rods cemented into ground.

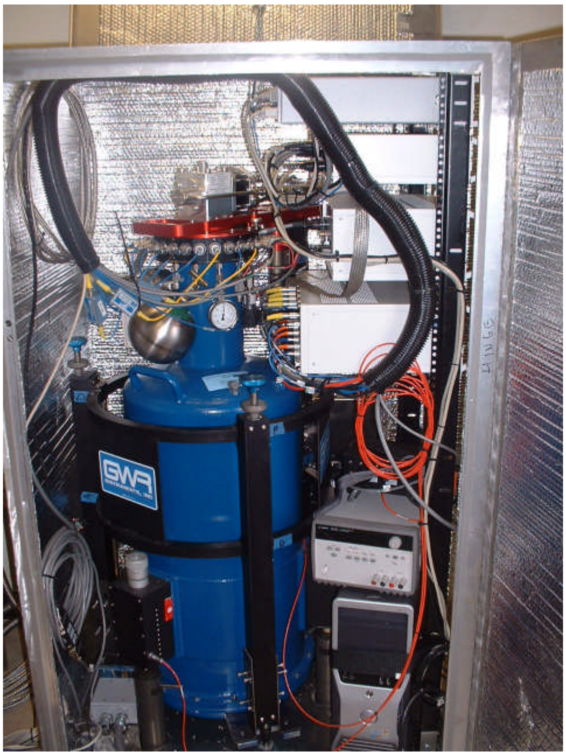


Figure 5: The gravimeter enclosure contains a standard SG, with rack mounted instruments. Transport requires locking the gravimeter dewar to the frame with brackets, and lifting off the gravimeter pillars. Relocations is accomplished with the proof mass suspended.

4. Assimilation of Gravity Data

A general method of assimilating data of various types into LSM's is the Ensemble Kalman Filter (EnKF) (Reichle et al, 2002). The method employs Monte Carlo experiments to estimate correlation coefficients between model state variables (such as soil moisture at individual grid points) and observations (such as GRACE or SG measurements). The EnKF adjusts model state variables using a linear combination of the difference between current model state predictions, and observed (GRACE or SG) data. Experiments with EnKF assimilation of GRACE data have shown promise. For example, Zaitchek et al, (2008) show that over the Mississippi basin, a useful improvement is provided by GRACE data. Unfortunately, GRACE monthly samples are mismatched in both temporal and spatial scales relative to typical data that are assimilated into LSM's, with spatial scales of km, and temporal scales of hours are more common. SG data have a similar scale mismatch, with spatial scales far smaller than typical data driving LSM's. There are efforts to develop new GRACE products with sampling rates of days, and methods based on mass concentrations as alternatives to spherical harmonic solutions. Such solutions may be able to take advantage of GRACE satellite passage within 1000 km of any point on Earth about once a day (Han et al, 2008). While efforts to improve the match in scales continues, the mismatch can still be handled using the EnKF approach as shown by Zaitcheck et al, so both SG and GRACE observations may be considered for assimilation as a future hydrologic data type.

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A new method for in-situ calibration of rod extensometers

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Abstract

At the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (GGRI) a new calibration apparatus was developed for in-situ calibration of extensometers. The calibrator contains a magnetostrictive actuator by means of which a known displacement can be produced as a reference pulse. Both this pulse and the displacement of the extensometer's end can be measured by the capacitive transducer of the calibrator. The sensitivity (scale factor) of the extensometer can be determined by comparison of the signals recorded by the calibrator and by the recorder of the extensometer.

1. Introduction

The measurement resolution of rod extensometers is better than 10^{-9} m. The in-situ calibration of these instruments represents a real problem since an absolute method by means of which such small displacements can be measured is not at our disposal. At the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (GGRI) a calibration apparatus was developed in 1982. This instrument was planned for testing crapaudines and magnetostrictive actuators which serve as built-in calibration device for regular daily calibrations of quartz-tube extensometers. At the same time this apparatus is also suitable for the in-situ calibration of quartz-tube extensometers. The high resolution of the device was achieved by two differential condensers, placed at the ends of a rotating arm. Disadvantage of this calibration instrument is that the extensometer must be connected to the rotating arm which causes some problems: instability of the coupling to the extensometer, small, sometimes insufficient place for the calibration apparatus on the extensometer pillar, etc. (Mentes, 1995a, 1995b, 1998; Mentes and Brimich, 1996). The above described disadvantages were eliminated by the development of a new calibration device which does not have moving mechanical parts, e.g. rotating arm.

In this paper the construction and calibration of the new calibration apparatus is described and the results of the in-situ calibration of the extensometer at the Geodynamical Observatory in Sopronbánfalva are also given.

2. Construction of the new calibration apparatus

Figure 1 shows the principle of the new calibration apparatus. One end of the magnetostrictive actuator is fixed to a rigid and very stable base plate which is standing on three foot screws. The other end of the actuator holds the two outer plates of a capacitive transducer, while its middle plate is fastened to the quartz-tube of the extensometer. Thus, the magnetostrictive actuator can move the outer plates of the differential condenser relative to the middle plate and the displacement can be measured by the capacitive transducer. The characteristic curve of the magnetostrictive actuator was measured by means of a HP5508 laser interferometer. On the basis of the measurements the connection between the current of the coil and the displacement produced by the core of the magnetostrictive actuator can be described by the equation:

$$d = 20.4541 + 5.4540 \cdot I + 0.0051 \cdot I^2,$$

where d is displacement [nm] and I is current [mA].

The capacitive transducer was also calibrated by a laser interferometer. The calibration apparatus was placed onto the stage and the middle plate of the transducer was fixed to the stand of a microscope. The calibration apparatus was moved by the micrometer screw of the microscope. The displacement of the outer plates of the capacitive transducer relative to the fixed middle plate was measured by the laser interferometer and by the capacitive transducer simultaneously (Fig. 2). The scale factor of the calibration apparatus calculated from the measurements is: -1.206 ± 0.002 nm/mV.

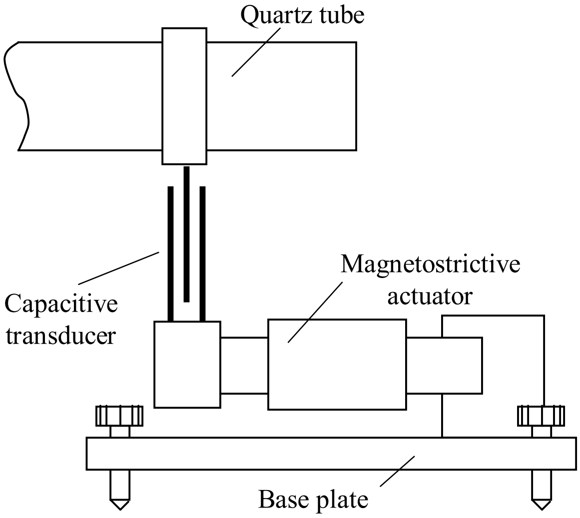

Fig.1. Principle of the calibration apparatus

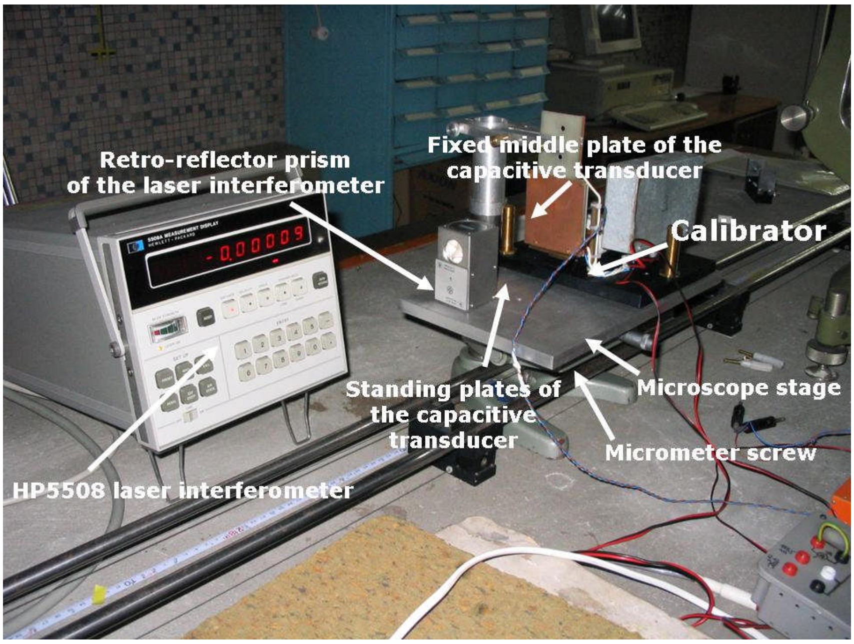

Fig. 2. Test of the calibration apparatus by means of the HP5508 laser interferometer

The scale factor of the calibration apparatus was also determined by another method as follows: the calibration apparatus was shifted to one end of the measuring range of the capacitive transducer by the micrometer screw. At this point a constant current ($I = 155.5\,\mathrm{mA}$) was periodically switched on and off to the coil of the magnetostrictive actuator. The magnitude of the displacement impulses was measured both electrically (c_i) – by the capacitive transducer – and by the laser interferometer (d_i). The average of both impulse series was calculated and the ratio of the average displacement measured by the interferometer ($\bar{d}_j$) and the average displacement measured by the capacitive transducer ($\bar{c}_j$) was calculated: ($s_j = \bar{d}_j / \bar{c}_j$). This value is the scale factor of the calibration apparatus at the given point of the measuring range. The scale factor was determined similarly at k ($j = 1 \ldots k$) points of the measuring range and an average scale factor ($\bar{s}_k$) was determined: -1.211 ± 0.021 nm/mV. The difference between the scale factors obtained by different measuring methods is within the error range of their determination. Since the error of the characteristic measurements is smaller than the impulse measurements, the scale factor: -1.206 ± 0.002 nm/mV was used for the calibration of extensometers.

3. Calibration of the extensometer at the Geodynamical Observatory in Sopronbánfalva

The principle of the calibration of rod extensometers is shown in Fig. 3. Displacement of the end of the extensometer is recorded both by the calibrator unit and the capacitive transducer of the extensometer. If the extensometer has a built-in magnetostrictive actuator for regular daily calibration, the sensitivity of the extensometer can be determined by means of parallel record of the calibration pulses produced by the built-in magnetostrictive actuator (Fig. 4). The sensitivity (scale factor) of the extensometer can be calculated by the comparing of the magnitudes of the recorded impulses. The scale factor of the extensometer is 2.093 ± 0.032 nm/mV.

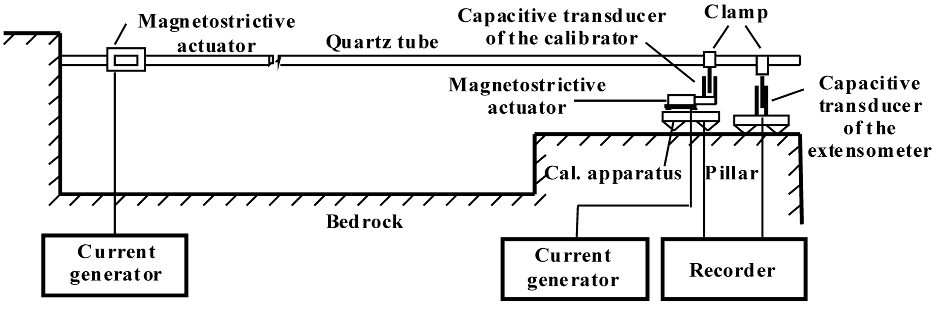

Fig. 3. Principle of the calibration of quartz-tube (rod) extensometers by means of the calibration apparatus

If the extensometer does not have a built-in magnetostrictive actuator, the comparison of the tidal curves recorded by the extensometer electronics and by the calibration apparatus (Fig. 5) can be used for the determination of the sensitivity of the extensometer. In this case the extensometer is calibrated by the magnetostrictive actuator of the calibration apparatus. The extensometer at the Sopronbánfalva Geodynamical Observatory was also calibrated by this method. The sensitivity of the extensometer is 2.119 ± 0.019 nm/mV. We can see that the difference of the scale factors measured by the two methods is within the error of their determination.

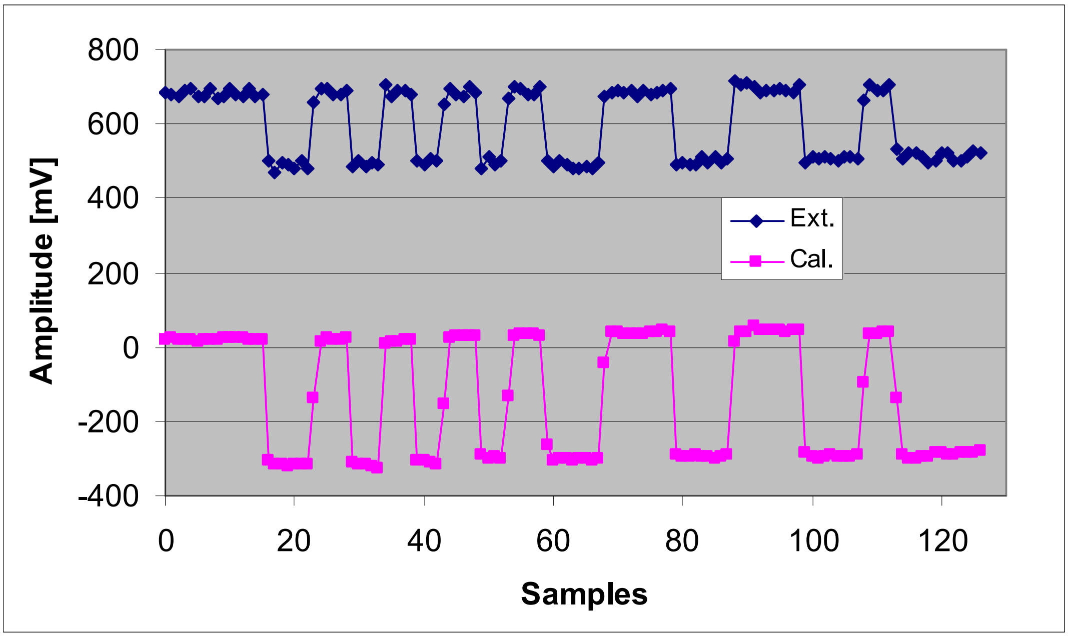

Fig. 4. Pulses of the built-in magnetostrictive actuator recorded by the extensometer electronics and by the calibrator apparatus

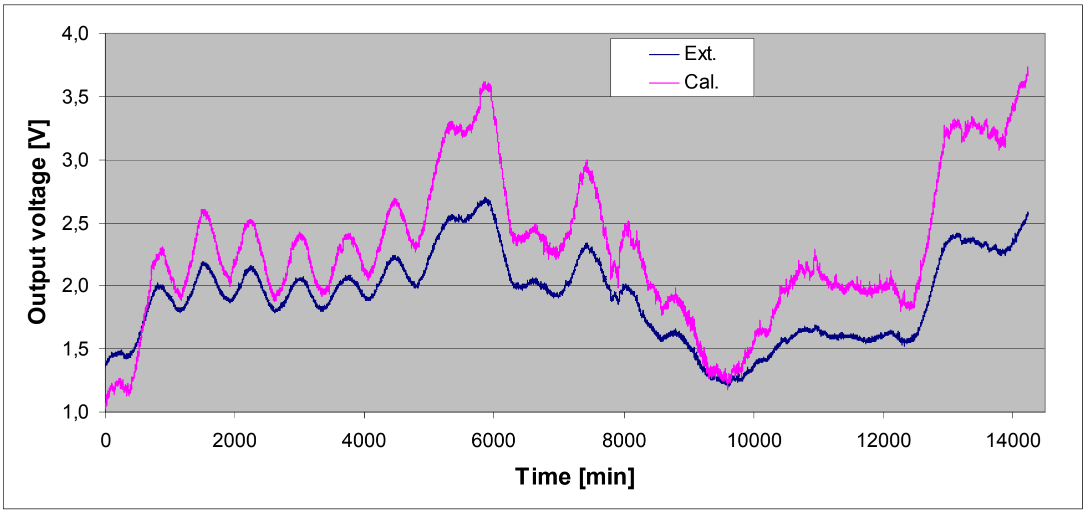

Fig. 5. Parallel tidal records made by the extensometer electronics and by the calibrator apparatus

Conclusions

As a result of instrumental development a calibration apparatus was constructed that has high accuracy owing to the fact that it does not contain moving mechanical parts. The installation of the new calibration apparatus is very easy and it is suitable for calibration of all types of extensometers including also invar wire extensometers.

Acknowledgements

This research was supported by the Hungarian National Scientific Research Fund (OTKA) in the frame of the research project K71952. The author is very grateful to Gerhard Jentzsch chair of the Department for Applied Geophysics, Friedrich-Schiller-University Jena, engineer Wernfrid Kühnel and technician Matthias Meininger (Geodynamical Observatory Moxa) for their help in the control calibration of the magnetostrictive actuator in the frame of the Scientific and Technological Cooperation between Germany and Hungary (Project number: in Hungary: D-8/99; in Germany: UNG-026-99). The author thanks to Tibor Molnár and Frigyes Bánfi for their help in the laboratory and observatory experiments.

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Paraconic Pendulum as precise Tiltmeter

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1. Introduction

High precision tilt measurements are necessary to solve a lot of problems in science, engineering, building, and so on. There are different kinds of tiltmeters to measure small tilts (amplitude till 0.05 arcsecond) of investigated objects: hydrostatic tiltmeter, which has a water as sensitive element; pendulum tiltmeters where the sensitive element is a pendulum suspended by thin metal thread, and others.

We experimented a possibility to use the paraconic pendulum device as tiltmeter. The sensitive element of such device is a paraconic pendulum – solid metal body with quartz rod and metal stirrup suspended to support plate by a small ball or knife free to roll on a horizontal support plate (Fig. 3); it has a minimal temperature coefficient, and a rigid structure.

The aim of our investigation is the registration by our device of small tilts of different kinds of objects (buildings, pedestals, bases and so on) in the range of tidal tilts of Earth surface. The investigation of tiltmeters the range of tidal tilts of Earth surface is not a trivial problem because it is necessary to preset a smooth sinusoidal signal with a very small amplitude – till 0.05 arcsecond.

The device was put on a horizontal tilting table, which can preset the angles of tilt in the range of tidal tilts of Earth surface, so we got the inclination of pendulum body relatively to its frame. To have a smooth tilting of our table in such small interval we use the Verbaandert bearing ("crapaudine") on which one of three plate feet was put. It's a metal cylinder with a thin upper wall (Fig.1, Melchior 1966).

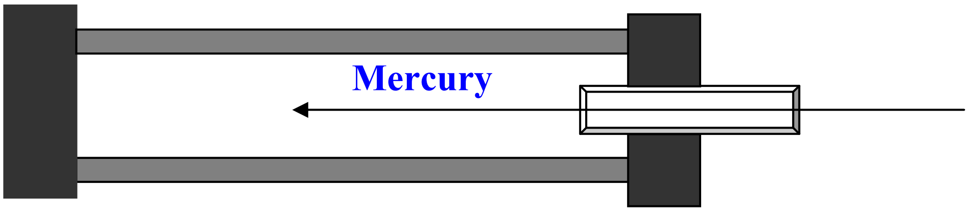

Figure 1: Principle of the Verbaandert bearing (inflatable "crapaudine")

The cylinder is connected through a plastic pipe with a vessel fastened on a rotating arm (Fig.2).

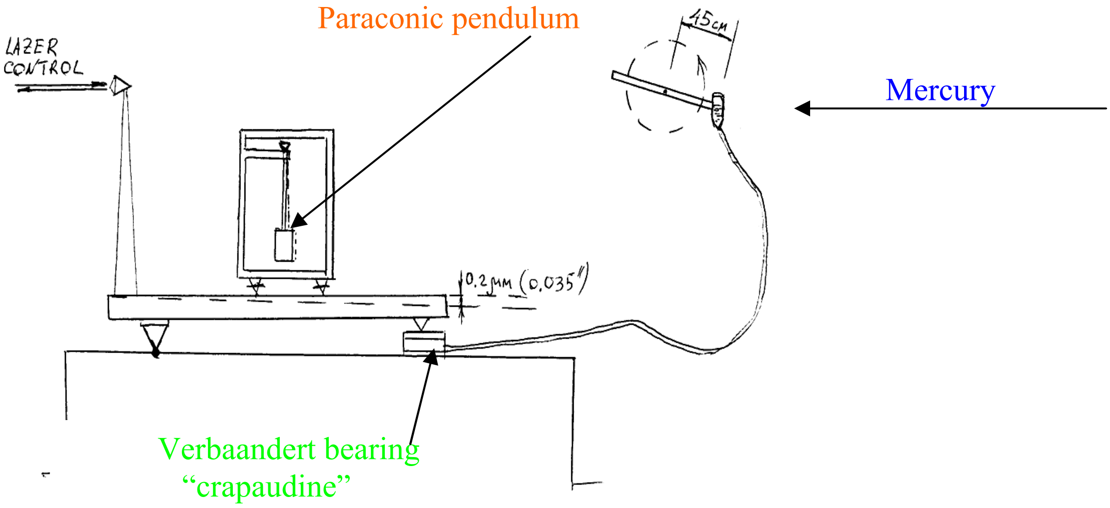

Figure 2: Principle of the tilting table

The vessel, pipe, and crapaudine are filled with mercury. The mercury in vessel communicates with the atmosphere. The change of the mercury pressure in the cylinder, produced by the rotation of the arm, deforms the upper wall as diaphragm. It bends till 100 nanometer, and lifts (or lowers) the foot of the tilting table. Fastening the mercury vessel in various positions on the arm we can modify the amplitude of the mercury pressure variations in the crapaudine and consequently the amplitude of tilt of the table. We chose a period of rotation of the arm equal to 15 min.

The motion of pendulum was registered by the capacitive displacement transducer (Nanoukin and Rebrov, 1982). It can register the change of distance between the pendulum lower body and the plates of measuring capacitor with resolution 10^{-10} m during 1 min in the range of 27 arcsecond. There are 4 plates fixed around the lower pendulum body in distance 0.5 mm to register the horizontal pendulum motion in two perpendicular planes (Fig.3).

We controlled the smooth rotation of the arm, the regular tilt of the table and the quality of the capacitive transducer by Michelson phototachymeter: a rod with a corner reflector was fixed on the tilting table. The angle of tilt of the base plate measured by interferometer was $(0.035 \pm 0.003)''$; the lower pendulum body displaced correspondingly of 40 nanometer.

Before experiment the capacitive displacement transducer was calibrated by static method with the device of horizontal displacements. To evaluate the investigated signal and noises we used the capacitive plates of the same area that for the experiment ($6 cm^2$).

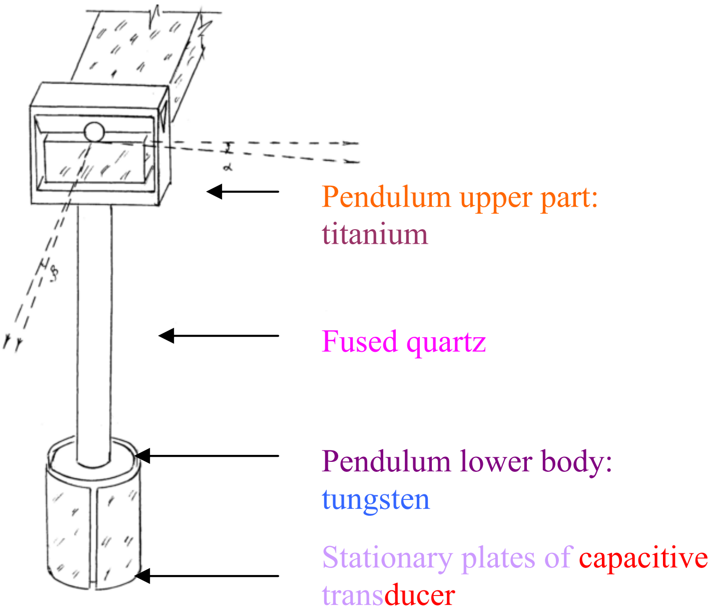

Figure 3: Schematics of the paraconic pendulum

2. Experimental results

In our experiment we used two types of pendulum suspension: the agate sphere and the agate knife, both supported by agate plate. We experimented also with two pendulums of the same construction for which the common regularities were determined. The curvature radiuses of pendulums were 5 and 7 µm. The experiment took place in the building basement on a concrete pedestal.

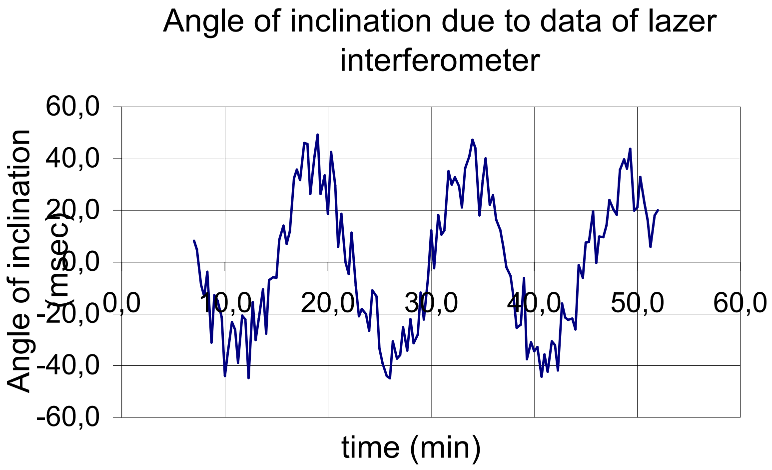

Figure 4: Calibration of the tilting table by means of Laser interferometer.

The tilting table was placed on the crapaudine, and then we measured by laser interferometer the amplitude and period of table tilts which proved to be (0.035±0.007)″ and (15±0.5) min correspondingly (Fig.4).

Spherical suspension

The tilts of pendulums were preset in one plane, and their recording was done in two perpendicular planes. We got as result that the preset tilts cause *parasitic tilts in the perpendicular plane* independently of the azimuth of the device. The amplitudes of parasitic tilts are *comparable* with the preset amplitudes. Even if sometimes there weren't any parasitic oscillation of pendulum in perpendicular plane, the oscillations of *"white noise"* type were always induced with amplitude (0.005 – 0.008)″. Mostly in the perpendicular plane there were the 1st and 2nd harmonics of preset tilts (Fig.5).

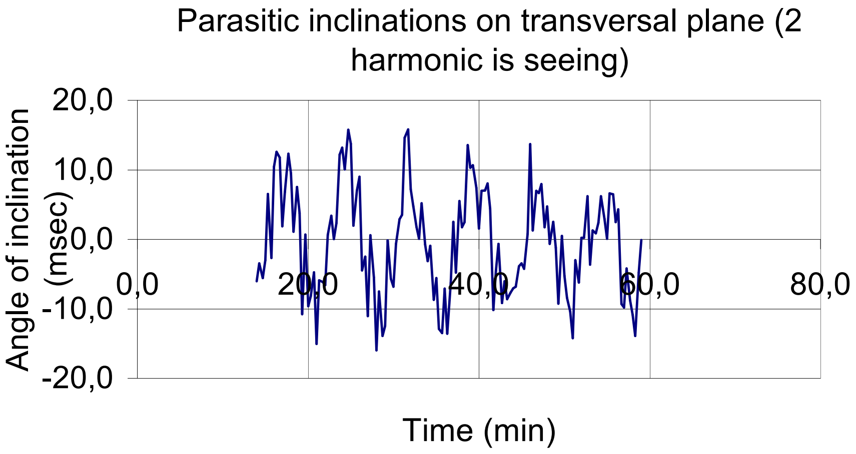

Figure 5: Parasitic inclinations in a direction orthogonal to tilt of platform.

The effect of transfer of pendulum oscillation from plane to plane depends strongly of the quality of treatment of the surfaces of pendulum suspension, and also of the material properties of surfaces. One may suppose that a spherical surface rolls on the plane *bearing on some surface and sphere imperfections* (Fig.6).

Let consider some variants of the positions of contact points. If their position is on the *straight line* in plane of given pendulum oscillations, the latter haven't to transfer from one plane to other. Such case was observed quite seldom. The recording corresponding to this position (see Fig.6a) is given on the Fig.7.

The recording in Fig.5 shows the case corresponding to the Fig.6c where one can see a *duplication of frequency*. All cases were experimentally observed with different azimuthal orientations of device. Because generally the preset tilts of the pendulum in one plane generate the tilts in transversal plane, a tiltmeter with spherical suspension is not of interest until the technology of fabrication of spherical surfaces will be improved.

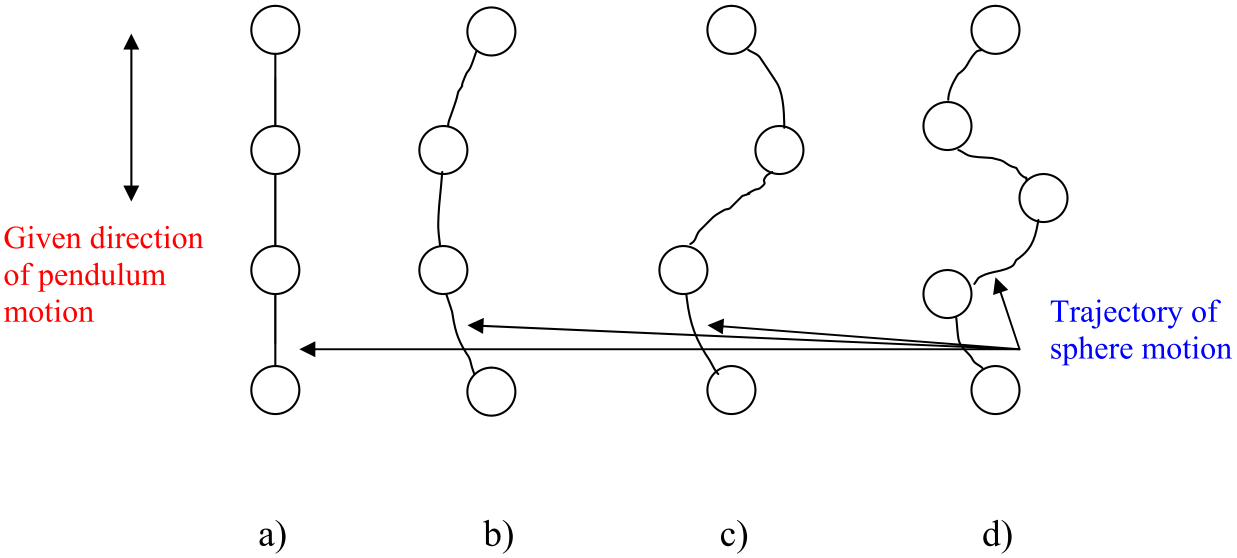

Figure 6: possible trajectories of the sphere on the agate plate.

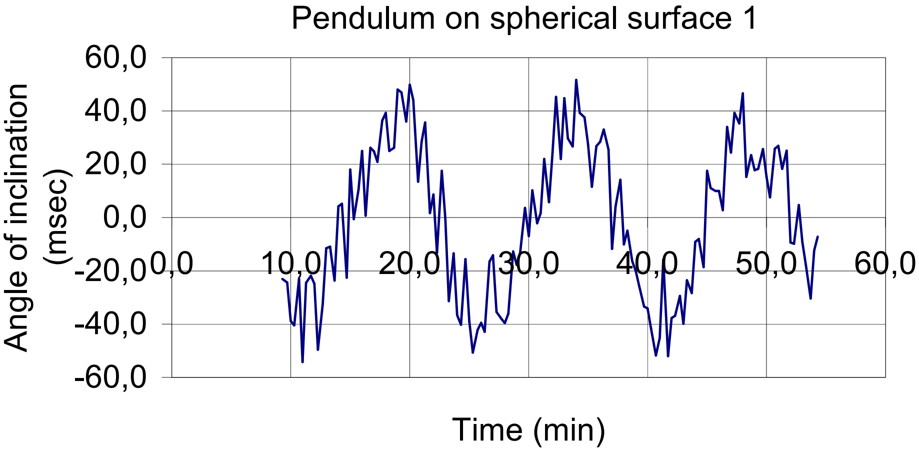

Figure 7: Recording of pendulum with spherical suspension in the direction of tilt.

Knife suspension

The radius of knife curvature was 10 µm, and the length of contact line with the plane was 40 mm; this secures the integrity of the interacting surfaces. By classic calculation (Panteleev, 1959) the decrease of amplitude doesn't exceed 1% for a curvature radius of 10 µm and a pendulum length of 25 cm.

An example of tilt change of pendulum on agate knife is shown in Fig.8.

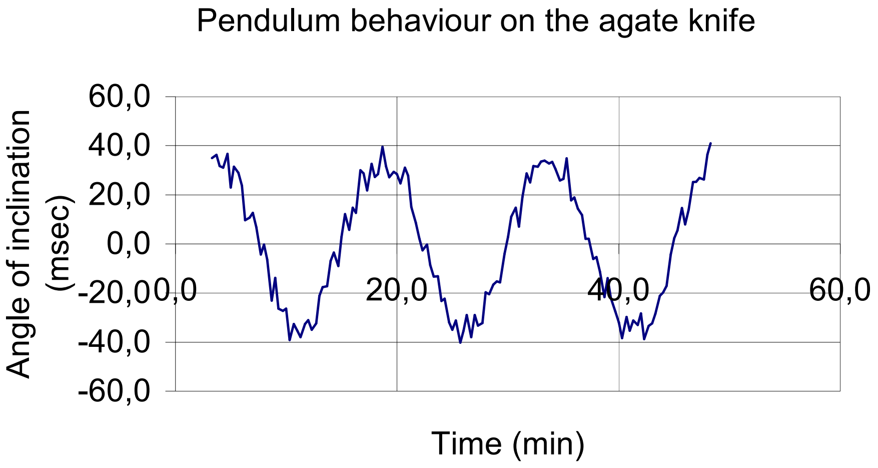

Figure 8: Recording of pendulum with agate knife in the direction of tilt.

One can see that the pendulum repeats a smooth sinusoidal signal given to the base by crapaudine with the error ± 0.003″. By the way the resolution limit of the registration system in our experiment permits to register values <u>one order of magnitude less</u>. The received error is related most likely with the quality of treatment of the agate knife and the agate plate on which the knife is rolling. So such pendulum device is a good tiltmeter. Its multiplying factor can be determined experimentally; it depends of tilts interval, multiplying factor of the capacity transformer of displacement, and the radius of knife curvature.

The temperature characteristics of the device, its nonlinearities, interval, resolution limit, and long term stability depend mainly of the characteristics of registration system, of the bonding technique of device on the investigated objects, and so on, and also of the quality and wear and tear of the knife blade and the plate. The construction of this device – in particular the area of contact of knife blade and the plate – is calculated specially for the optimization of the working life of device. The testing was made for big angles of oscillation during hundred hours with a constant control of the change of curvature radius of the knife blade.

Our angles of oscillation are four order less, that's why the long term stability of such tiltmeter related with wear and tear of the knife and plate must be very high.

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Tilt observations and finite-element-modelling of deformation and stress, induced by the large scale injection experiment at the KTB/Germany[1][2])

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Abstract

In earthquake research and investigations associated with accumulation of stress in the Earth's crust the role of fluids became more and more important in the last years. However, the interaction of deformation, fluid migration and stress accumulation in the crust is still poorly known. Therefore, in a large scale injection experiment at the deep borehole-site KTB (Kontinentale Tiefbohrung der Bundesrepublik Deutschland) in Germany water was injected into the 4,000m deep pilot borehole for ten months. The fluid induced pore pressure change caused a deformation of the upper crust which was detected by the KTB tiltmeter array, consisting of five high resolution borehole tiltmeters of the ASKANIA type with a resolution of 0.2 msec (~ 1nrad). In parallel the induced seismicity was monitored by a local network and by a borehole geophone in the KTB main borehole (HB) (Shapiro et al. 2006).

A numerical modelling of the deformation revealed an uplift of more than 3mm in the centre of the investigation area above the injection point. Other modelling results regarding the pore pressure distribution, the fluid velocity and particularly the influence of the modelled fault zone are achieved. The region of the induced maximum deformation is nearly identical with the region covering the induced earthquakes. Further, a correlation to the local fault structure is obvious. Thus, surface tilt observation in connection with finite-element modelling proved to be a tool for the investigation of the geodynamic process. This procedure enables a more sophisticated geodynamic interpretation of coupled source processes, and can be applied in active tectonic and high risk areas.

1. Introduction

Close to the super deep drillhole KTB (Kontinentale Tiefbohrung der Bundesrepublik Deutschland) with a depth of 9,101 m fresh water was injected into the pilot borehole (distance 200m) in a depth of 4,000m. The injection at the KTB was realised continuously over 10 months and several geoscientific projects were based on this experiment (Kümpel et al. 2006). In the frame of the tilt project, the induced deformation of the surface around the injection point was observed and modelled using the finite-element-method (FEM).

A tiltmeter array, consisting of 5 high resolution tiltmeter, was designed and installed in the surrounding of the KTB. These stations were located in distances between 1.6 km and 3 km from KTB (Fig. 1). In addition, the local ground water levels were observed at all stations (Zeumann et al. submitted to J. Geodynamics). In the last step the geodynamic process was interpreted regarding the fluid situation with pore pressure changes and the total stress- and strain fields.

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[1] The detailed results of this research project is published in Jahr et al. 2008 (s. references)

[2] Co-author Tobias Stacke has changed his name from formerly Tobias Lau in Sept. 2008

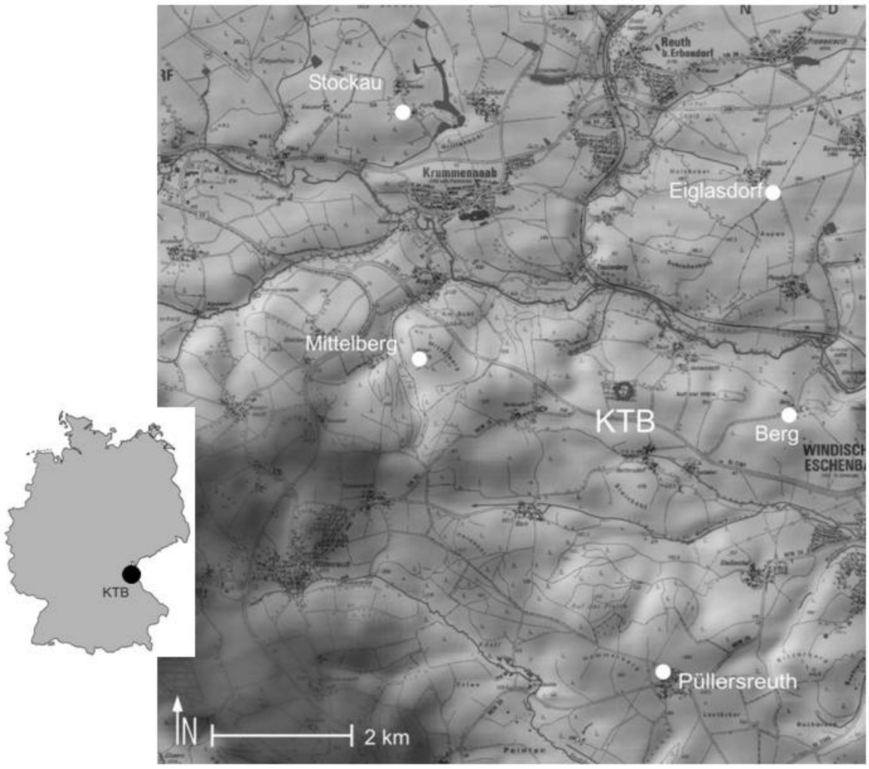

Figure 1: Locations of stations of the tiltmeter-array around the superdeep drillhole KTB/Germany. The tiltmeters are installed in approx. 40m deep boreholes, and the data are transferred by a wireless LAN to KTB and by internet to the institute in Jena.

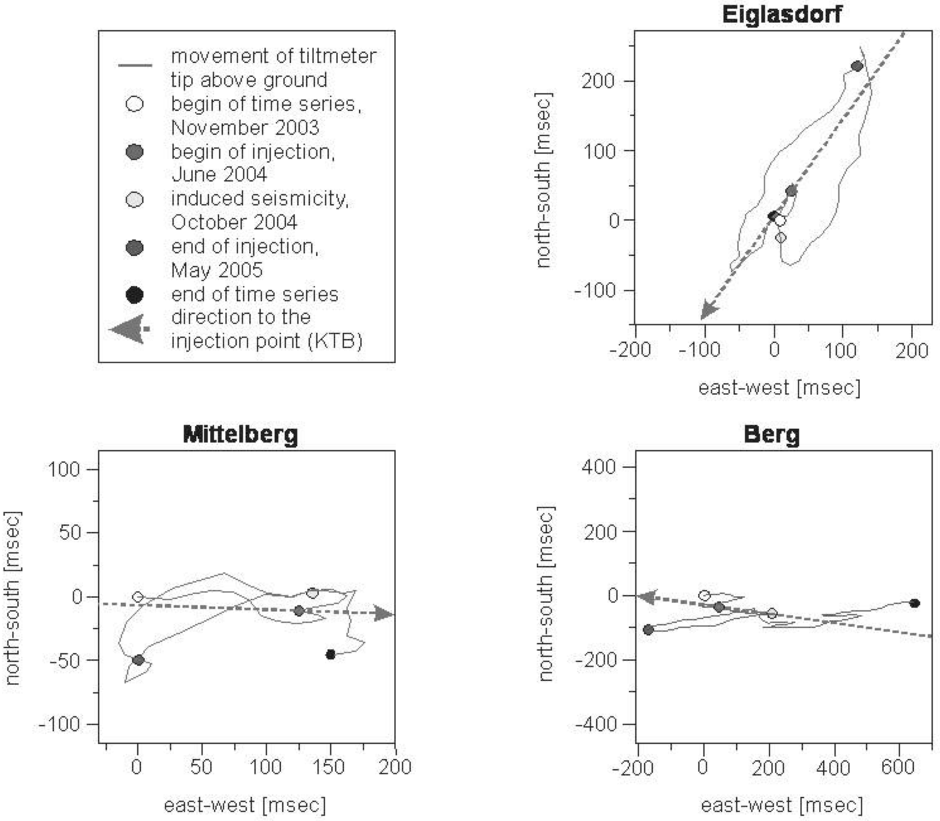

Figure 2: Hodographs, showing the movement of tips of pendulums above ground. It is clearly shown, that during the one year injection period the movements are correlated with the direction to the injection point (dotted arrows).

The design of the tiltmeter array, the observed time series, the data processing, and the tidal analysis are described by Jahr et al. (2005, 2006). The analysis of the observed free modes after the huge earthquake in December 26, 2004 is summarized by Jentzsch et al. (2005). The used ASKANIA tiltmeter is discussed by Gebauer et al. (2007) and results including the modelling is given by Jahr et al. (2008). The interpretation presented here is based on two points: The first one is the observation of the induced deformation, the other one is the numerical modelling using finite-element-method.

2. Experiment and observations

The tiltmeter array around KTB is shown in Fig. 1. The instruments were installed in approx. 35 m deep boreholes in order to avoid meteorological influences. The resolution of this pendulum-type tiltmeter is better than 0.2 msec or 1 nano-radian (nrad).

The measured tiltmeter data were tide reduced and afterwards used to generate hodographs, which show the movement of the pendulum tip above ground (Fig. 2). The axes are given in milli-arcseconds (msec), and the tides are reduced in the tilt data. The arrows point to the injection at KTB and it is clearly visible that during the injection the tips of the pendulums are moving in direction of the injection point. This was observed only at three of five stations because of circumstances beyond our control: One station was destroyed by lightning and another one was strongly influenced by local ground water level variations. Nevertheless, the three stations detected significantly the bulge, induced by the injection.

For a homogeneous underground an injection bulge would generate tilt change orientations radially symmetric to the injection point. But the area of KTB is characterized by the main fault zones, the Altenparkstein fault zone and the Waldeck-Klobenreuth fault zone (hereafter SE1 and SE2), and additionally by local faults with different strike directions. Therefore a numerical model was created to explain the order of the observed injection induced tilt amplitude and the discrepancies against the pure radial symmetry.

3. Geology and finite-element-model

The regional geology around KTB is dominated by granites. Beside them the fault zones are the most important geological feature. They are well known from extensive seismic pre-investigations before the KTB super deep drilling started (Emmermann and Lauterjung 1997). The SE1 and SE2 reflectors represent the well known Franconian Line fault in this area.

These fault zones are implemented in the 3-dimensional FE-model with a simplified geometry (Fig. 3). The model also includes the injection borehole (white star in Fig. 3) in its center, surrounded by the tiltmeter array (black stars). Remarkable is the fact, that the injection point in 4 km depth is located very close to the crosspoint of the SE2 fault and the Nottersdorf fault (Nds).

The FE-mesh of the model comprises 54,000 elements of the hexahedron type. The fault zones are parameterised by increased permeability up to factor 1,000 compared to the adjacent rocks (Gräsle et al. 2006). The model is loaded in three steps for gravity, the regional stress field and the injection over 10 months.

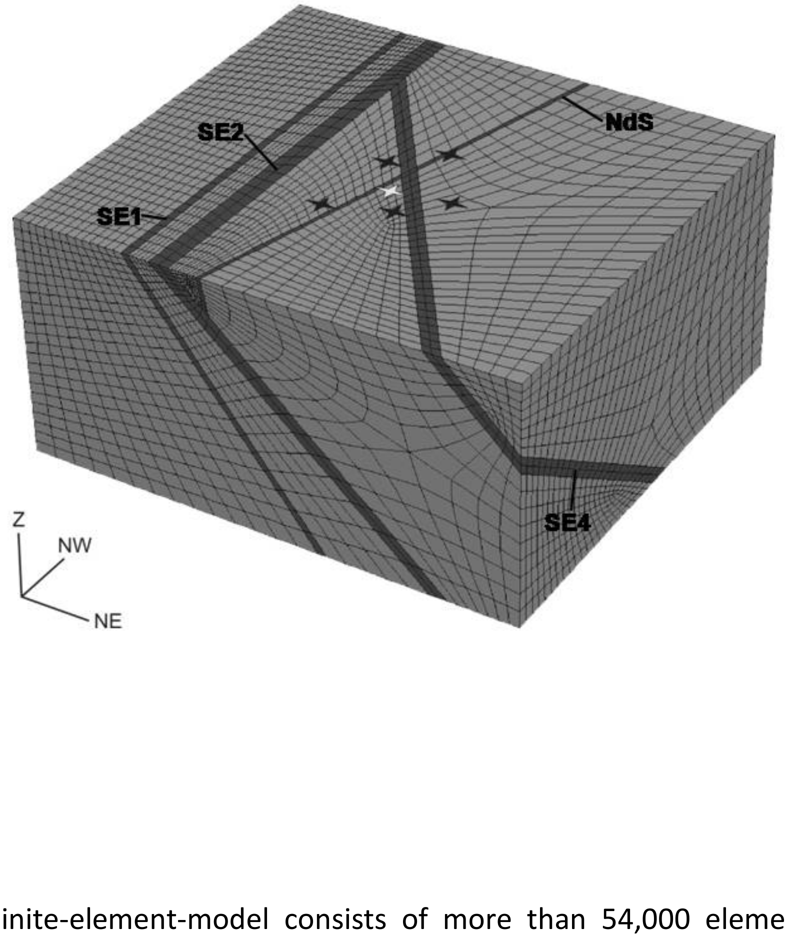

Figure 3: The Finite-element-model consists of more than 54,000 elements and has an extension of 18 x 20 x 10 km³. The injection borehole is marked by a white star and the tiltmeter stations by dark stars. The main fault zones SE1, SE2, SE4 and Nds of this area are included (dark elements). The injection took place in 4 km depth.

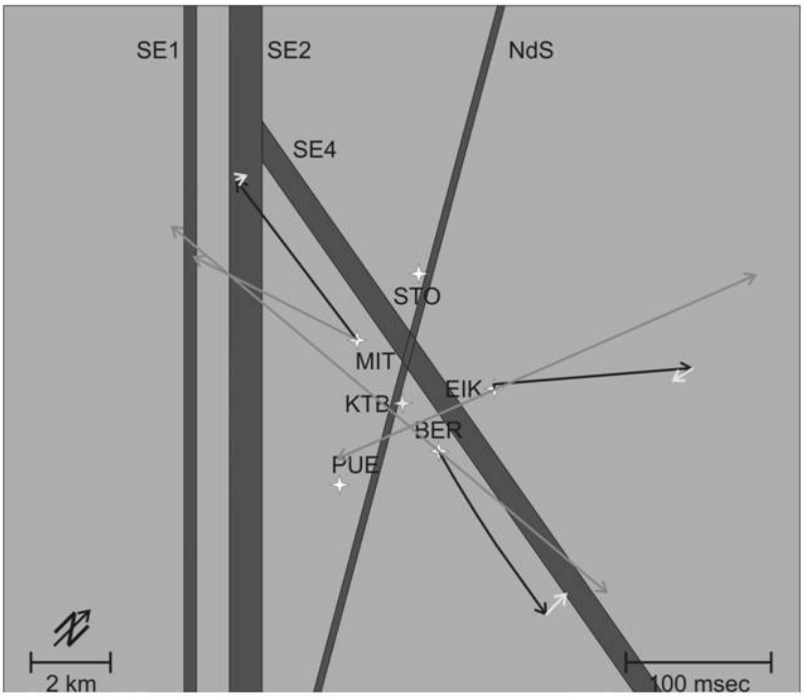

Figure 4: Surface plot of the modelled injection induced tilts (dark arrows) compared to the observed tilts (gray arrows). After end of injection the tilts changed in direction marked by the white arrows. Maximum amplitude discrepancies are shown for station EIK (60 msec), maximum phase shifts for MIT (30°).

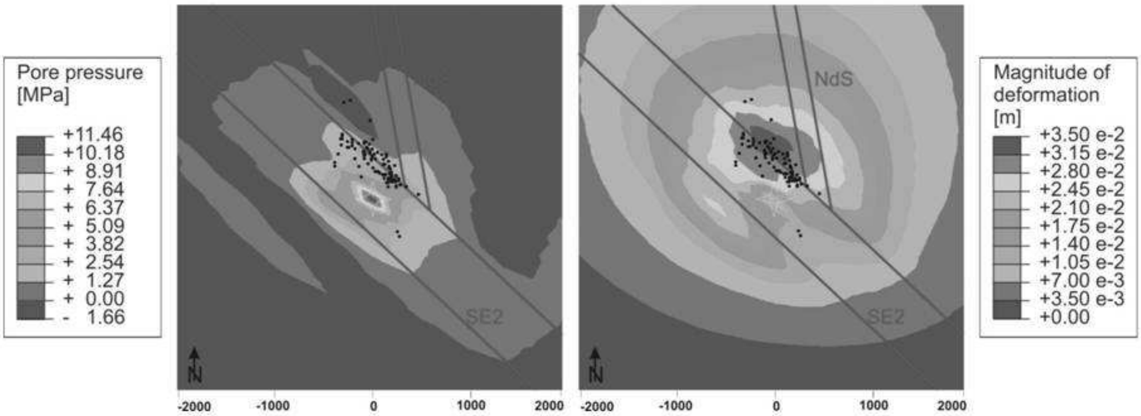

Figure 5: Correlation between the locations of induced seismic events and pore pressure distribution (left side) and deformation (right side) in the depth of the injection point (4 km). The induced seismicity is highly correlated with the deformation, calculated by the FE-modelling (after Jahr et al. 2008).

4. Results and interpretation

The computed maximum uplift, due to the injection, is 3.2 mm above the injection point. More than 150 msec tilt changes are calculated in the surrounding of the injection, whereas the areas of maximum tilt gradients are correlated with the NW-SE striking SE2 and the EW-striking Fichtelnaab (SE4) faults. The evolution of deformation field due to the injection shows, that the tilt increase does not stop at the end of the injection. It goes on during the relaxation process. This result was confirmed by the observations.

The comparison of the observed and the modelled tilt yields a high correlation regarding the amplitudes and the orientations (Figure 4). Maximum discrepancies are 60 msec in tilt change amplitude for station Eiglasdorf and 30° in tilt change orientation for Mittelberg. This result confirms, that the modelling can explain the main part of the injection process. The influences of the faults on the pore pressure can be demonstrated by comparison with the homogeneous case: If the fault zones are "switch on" in the model the stress increases in the surroundings of the injection point by more than 20%, because the stress field is now concentrated to the faults zones SE2 and NdS. As expected, the induced pore pressure has maximum values directly at the injection point in 4 km depth, while the induced maximum (total) deformation is situated north of the injection point, close to the cross-point of SE2 and NDS faults.

This area of maximum simulated deformation is exactly identical with the region where the induced seismicity occurred about three months after the beginning of the injection (Fig. 5). This region is located at the northern border of the SE2 fault zone close to the crossing edge with the NdS fault. The seismicity was observed by our colleagues from Potsdam and Berlin (Shapiro et al. 2006). Therefore the model is able to capture the interaction between fluid injection, maximum deformation and seismicity.

5. Conclusion

Five points can be concluded:

- the induced deformation was detectable by the tiltmeter array,
- the modelling shows that the whole process is controlled by the fault zones,
- the modelled tilts changes fit to the observed ones in amplitude and orientation,
- the area of maximum deformation is highly correlated with the occurrence of induced seismicity, and
- the procedure presented here is a helpful tool esp. for the investigation of fluid processes in tectonic active areas.

6. Acknowledgement

This project and the injection at the KTB were financially supported by the Deutsche Forschungsgemeinschaft and the GeoForschungsZentrum Potsdam. This is gratefully acknowledged. We thank the farmers for the allowance to install and to operate our stations on their properties. Dr. Horst Letz, Manfred Brunner, Wernfrid Kühnel, and Matthias Meininger installed and maintained the tiltmeter array, which is gratefully acknowledged.

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STRUCTURAL-GEOLOGICAL AND LITHOSPHERIC FACTORS AFFECTING DEFORMATIONS OF THE UPPER CRUST

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Extended Abstract

Deformations are observable by various kinds of geodetic and geophysical instruments, e.g. strainmeters, tiltmeters, seismometers, permanent GPS-stations. The present study focuses on horizontal deformation components. The observed deformation contains signals of different amplitudes and greatly diverse origin:

- periodic signals (tides, …)
- aperiodic signals (tectonics, …)
- local influences (cavity effect, topographic effect, …)

The periodic and aperiodic signals have been investigated in several studies, for e.g. the tides (Zürn, 1997). From these investigations emerges, that many influences caused by local surroundings of the instrument can be some orders larger than the signals of interest. The locally induced deformations are related to the gallery geometry (cavity effect), to topographic features, structural-geological and lithologic factors for hydrologic, and atmospheric as well as tidal and ocean loading (e.g. Harrison, 1976; Harrison & Herbst 1977). Likewise temperature-related influences are found.

A number of studies have been carried out in order to determine the magnitude of the effects originating from the surroundings of an instrument location and influencing seismometer, tilt- or strainmeter observations (e.g. Kroner et al., 2005; Steffen, 2006; Steffen et al., 2006).

Recently, the studies related to atmospheric load have been continued and extended. The influence of several factors has been investigated systematically. The objective of this principle study is to determine the order of magnitude and the transfer mechanisms. The results are used to improve reduction methods related to deformations caused by effects of the local observatory surroundings and to provide a physical basis for the development of new algorithms. Furthermore, criteria are inferred for selecting locations of new observatory sites.

Elastic models are developed using the Finite Element software ABAQUS. The dimension of the models is 5 km x 5 km x 1.6 km. For loading two different barometric pressure scenarios are considered: a uniform load and a high pressure area moving across the model in different directions, both with an amplitude of 1 hPa. Since elastic rheology is used, the modelled deformations are scaleable according to different load amplitudes.

In the galleries, which are included in the models perpendicular to the topography, an instrumentation of strain- and tiltmeters is assumed. The strainmeters are 'installed' at the bottom of the gallery cut inside the slope and on the model surface (Fig. 1), oriented either parallel or perpendicular to the gallery. Tiltmeters are 'installed' in boreholes. The instruments have a nominal resolution of 0.2 nstrain and 1 nrad.

The influence of cavities is investigated for different gallery lengths and thicknesses of the coverage above the gallery. The topographic influence is studied with respect to rock coverage of an observation site, changes in the sloping of a hill flank or width of a valley (Gebauer et al., 2009). For this part of the investigations all models are parameterized after PREM (Dziewonski & Anderson, 1981). The result with respect to changes in the slope angle is given in Fig. 1. The slope angle is changed between 15° and 90° in 5° steps. At the foot of the slope in the centre of the model a 50 m long gallery with a quadratic cross section of 2 m x 2 m (Fig.1 d) is incorporated. The barometric pressure load acts always normal to the surface. For small slope angles the barometric pressure has basically a vertical component and for larger angles the horizontal component dominates. The deformations for the strain- and tiltmeter located in front of the gallery are used for comparison (Fig.1 d). For increased slope angles a non-linear increase of the deformation amplitudes perpendicular to topography occurs (Fig.1 a). For the strainmeter dilatations in the range of 0.4 and 0.7 nstrain are obtained. For larger slope angles than about 50° the influence of the slope is nearly constant. The amplitudes for the tiltmeter range between 0.07 and 0.35 nrad, in which the bottom of the tiltmeter moves away from the slope with respect to its top.

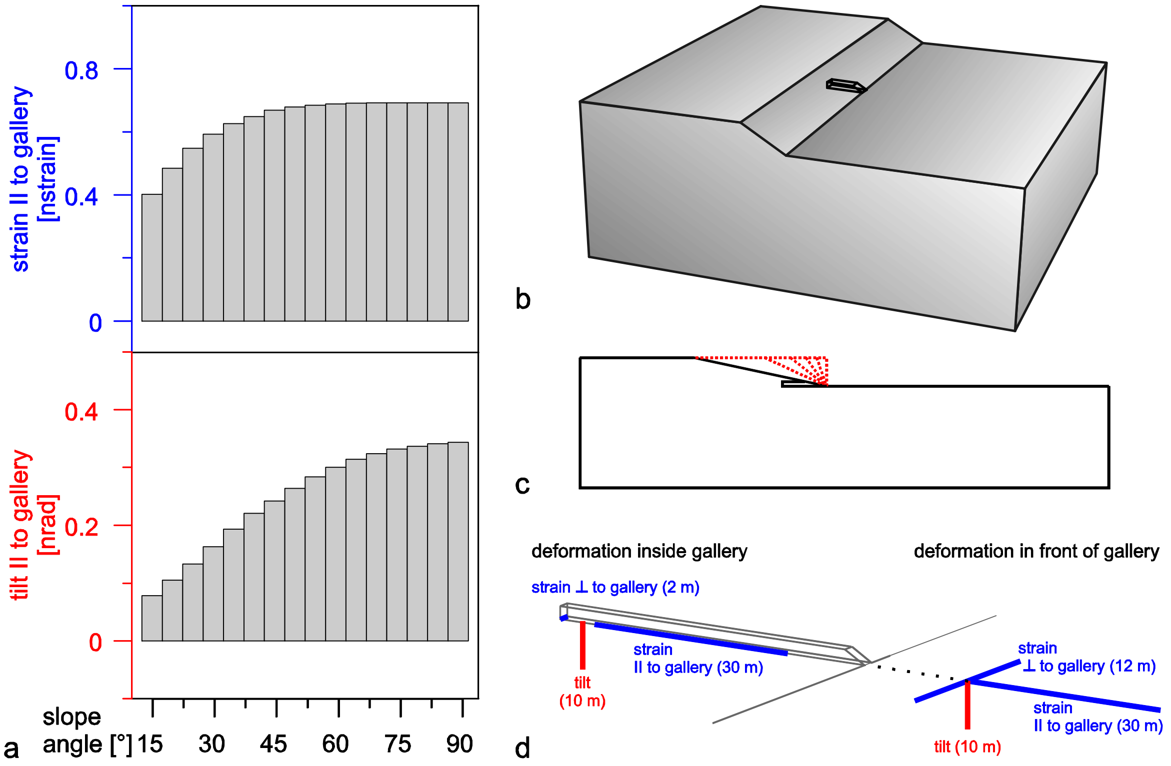

Fig. 1: Determined deformation (a) for a slope model (b) related to a changing slope angle (c). The deformation additionally is determined in front of the gallery (d) as reference.

The systematic study has been extended to the effect of local geological heterogeneities such as different lithological units and faults. The findings of the study regarding different influencing factors are summarized in Tab. 1.

Tab. 1: Maximum amplitudes of the different effects calculated in the principle study for 1 hPa barometric pressure load.

effect	strain [nstrain]	tilt [nrad]
cavity	0.5	1
topography	2	2
lithology	3	7
fault	7	2

For the analysis and interpretation of deformation observations all of the effects are significant. Generally, the deformation components oriented perpendicularly to topographic (hill flanks) or geologic features show the biggest influences. The various effects overlap in the observations in a complex way. Thus, a separation of the different effects in the data is difficult and therefore a better understanding can only be realized by modeling.

In a further step the investigations have been applied to the observatories of Wettzell, Sopron, Moxa, and Schiltach. All these observatories show characteristic topographies and comprehensive information on station conditions is available. The model topographies are realized based on digital terrain models (DTM). The models include the real galleries and instrumentation. From the studies it is found that even small topographic features like scarps in the local vicinity can produce strong deformations.

The investigations related to local influences will be continued and also extended to influences on regional scale. For this a model of central Europe will be developed.

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The Wettzell Ring Laser “G” as a North-South Tilt Probe

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Summary : The ring laser “G” located in Wettzell, Germany, is a north-south tilt probe for periods between one hour and two days, after removing all nuisance components, especially the part arising due to Earth orientation variations. In contrast to high-sensitive tiltmeters, the ring laser does only sense tilts induced by deformation (no attraction), and is therefore a function of the potential Love and Shida numbers h_2 and l_2, while tiltmeters do include the Love number k_2. The optimum Love numbers, derived from the “G” ring laser and the nearby tiltmeter, are $h_2 = 0.6573$, and $k_2 = 0.3577$. This result is obtained for a fixed nominal value $l_2 = 0.0847$.

1. Introduction

In principle, deformations of the Earth’s surface induce changes in the local vertical. A lunar signal has been predicted for large ring laser gyroscopes [Rautenberg et al., 1997], and this has been detected recently for the first time for the C-II ring laser, located in Cashmere, Christchurch, New Zealand [Schreiber et al., 2003]. In the last years, a new prototype, the “G” ring laser in Wettzell, Germany, has proven highest accuracy and resolution in detecting signatures in Earth orientation [Schreiber et al., 2004].

2. The Wettzell ring laser “G” and the Sagnac frequency

The Wettzell ring laser “G” (see figure 1) is a sensor using the Sagnac effect [Anderson et al., 1994] and being in operation since the year 2001 [Schreiber et al., 2008]. Its size is 4m x 4m consisting basically of the glass ceramic Zerodur due to the extreme mechanical and thermal stability that is required. It is located in an underground laboratory operating in stable thermal conditions. The main functioning is as follows: two counter-rotating laser beams are splitted by frequency if a rotation occurs. In such a case a beat frequency can be observed, and is called Sagnac frequency f. This beat frequency is inverse proportional to the perimeter of the beam path length P and the optical wavelength λ, and proportional to the enclosed area A, the normal vector $\boldsymbol{n}$ to A, and finally to the instantaneous rotation vector $\boldsymbol{\Omega}$ of the Earth [Schreiber et al., 2003]:

$$f = \frac{4 \cdot A}{\lambda \cdot P} \cdot \boldsymbol{n}^{T} \cdot \boldsymbol{\Omega} \qquad (1)$$

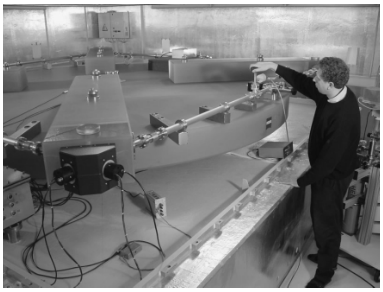


Figure 1 The Wettzell “G” ring laser adjusted by Prof. Schreiber.

3. The rotational perturbation in the relative Sagnac frequency

Earth orientation data and models

Earth orientation is commonly described by 5 parameters, two associated with the motion of the Celestial Intermediate Pole (CIP) in space, one for the Earth's angle of spin and two for the terrestrial motion of the CIP [Capitaine et al., 2002], see figure 2. And, this description is quite practical. However, such a parameterization requires a conventional distinction between high-frequency polar motion and nutation: precession-nutation is the terrestrial retrograde motion of the CIP with frequencies between one cycle in 48 hours and one cycle in 16 hours (sidereal), while all other motions of the CIP are interpreted as polar motion. Let $\mathbf{M}$ be the matrix for the coordinate transformation from the ITRS (International Terrestrial Reference System) to the GCRS (Geocentric Celestial Reference System). The realized CIP is defined through the computed equatorial components, X and Y, of the mean geographic axis in the GCRS by the IAU2000 precession-nutation model. The offset between this computed position of the CIP and the estimated one is called "celestial pole offset", with the components $\delta\mathrm{X}$ and $\delta\mathrm{Y}$. The equatorial position of the CIP in space is therefore composed of the computed CIP plus the celestial pole offset, and of the complementary terms, which are usually provided w.r.t. the ITRS. The latter are the terrestrial coordinates $\mathrm{p} = \mathrm{x} - \mathrm{i} \cdot \mathrm{y}$ of the CIP. The adopted transformation matrix $\mathbf{M}$, referred to the non-rotating origin, is given by:

$$\mathbf{M} = \mathbf{PN}(\mathrm{X} + \delta\mathrm{X}, \mathrm{Y} + \delta\mathrm{Y}) \cdot \mathbf{R}(\Omega \cdot \mathrm{UT1}) \cdot \mathbf{W}(\mathrm{x}, \mathrm{y}) \qquad (2)$$

where $\mathbf{PN}$ is related with the precession-nutation model and the celestial pole offsets, $\mathbf{R}$ to the angle of rotation around the CIP and $\mathbf{W}$ to the terrestrial position of the CIP.

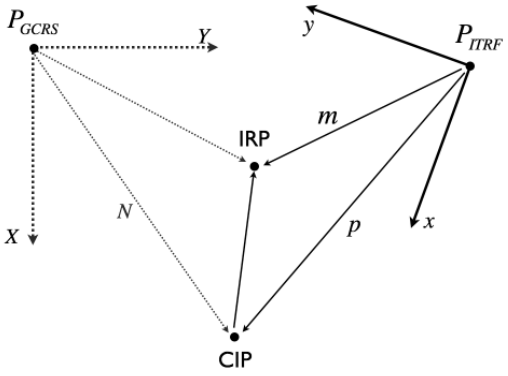


Figure 2 Celestial Intermediate Pole (CIP) versus Instantaneous Rotation Pole (IRP). Precession-nutation of the CIP is denoted by *N*.

Through the International Earth Rotation and Reference systems Service (IERS), the daily corrections $(\delta\mathrm{X}, \delta\mathrm{Y})$, $\mathrm{UT1\text{-}UTC}$ and (x, y) are available (EOPC04 05). We note that the zonal tidal terms are already included in the $\mathrm{UT1\text{-}UTC}$ time series. Then, the five parameters of each series are interpolated by using cubic spline functions at 30-minutes intervals. Our investigation is restricted to the time span from September 22nd 2006 (MJD 54000) to February 13th 2007 (MJD 54144).

In addition, we have taken into consideration diurnal and subdiurnal signatures. The diurnal (prograde) and semi-diurnal (pro- and retrograde) effect of ocean tides (71 tidal constituents) has to be computed, at 30 minutes intervals, for both the Earth rotation angle $\mathrm{UT1}$ and the polar motion ($\mathrm{p} = \mathrm{x} - \mathrm{i} \cdot \mathrm{y}$) of the CIP [IERS Conventions, 2004]. Moreover, retrograde diurnal (nutation) terms due to tidal gravitation (lunisolar) need to be computed for the polar motion of the CIP. So far, no official model is available for the effect of Earth's multipole structure upon its rotation angle. However, the model of [Wünsch, 1991] has been applied, as this effect may reach up to 3 µs in UT1.

Transformation to the instantaneous Earth rotation vector

The components of the instantaneous rotation vector (at a temporal resolution of 30 minutes) are directly calculated from the product of the matrices $\dot{\mathbf{M}}$ and $\mathbf{M}^{\mathrm{T}}$. In the terrestrial frame, we have:

$$M^T \cdot \dot{M} = \begin{bmatrix} 0 & -\Omega_z & \Omega_y \\ \Omega_z & 0 & -\Omega_x \\ -\Omega_y & \Omega_x & 0 \end{bmatrix} \tag{3}$$

The terrestrial coordinates of the instantaneous pole of rotation (IRP) are defined through:

$$\vec{\Omega} = \begin{pmatrix} \Omega_x \\ \Omega_y \\ \Omega_z \end{pmatrix} = \Omega_0 \cdot \begin{pmatrix} m_x \\ m_y \\ 1 + m_z \end{pmatrix} \tag{4}$$

The separation of the motion of the IRP into its various components has been developed in the last decades in great detail, e.g., [Brzezinski, 1986; Gross, 1992; Brzezinski and Capitaine, 1993].

The determination of high frequency variations of the IRP from VLBI data is described in a clear fashion by [Bolotin et al., 1997]. The use of the instantaneous Earth rotation vector in the reduction of superconducting gravimetry observations has been applied first by [Loyer et al., 1999].

Transformation to the relative Sagnac frequency

The relative Sagnac frequency is defined as:

$$\Delta f = \frac{f - f_0}{f_0} \tag{5}$$

where f_0 is the nominal Sagnac frequency for the ring laser "G" at Wettzell. If we assume that the perimeter of the beam path length P, the optical wavelength λ, and the enclosed area A are highly stable, then the relative Sagnac frequency is given to first order by [Mendes Cerveira et al., 2008]:

$$\begin{aligned} \Delta f &\approx \frac{\Delta \boldsymbol{n}^T \cdot \boldsymbol{\Omega_0} + \boldsymbol{n_0}^T \cdot \Delta \boldsymbol{\Omega}}{\boldsymbol{n_0}^T \cdot \boldsymbol{\Omega_0}} \\ &\approx \cot \varphi_0 \cdot \left[m_x \cdot \cos \lambda_0 + m_y \cdot \sin \lambda_0 + \Delta \varphi_{top} \right] + m_z \end{aligned} \tag{6}$$

where φ_0 and λ_0 are the nominal latitude and longitude of the ring laser "G", $\Delta\varphi_{top}$ is the topocentric latitudinal deflection (tilt), $\boldsymbol{\Omega_0}$ is the nominal Earth rotation vector, $\Delta\boldsymbol{\Omega}$ its perturbation, and $\boldsymbol{n_0}$ is the nominal unitary normal vector and $\Delta\boldsymbol{n}$ its perturbation. The component m_z is directly related to the excess length of day (LOD) [Gross, 2007]. Figure 3 classifies the relative Sagnac frequency variation due to Earth orientation changes into its sub-components.

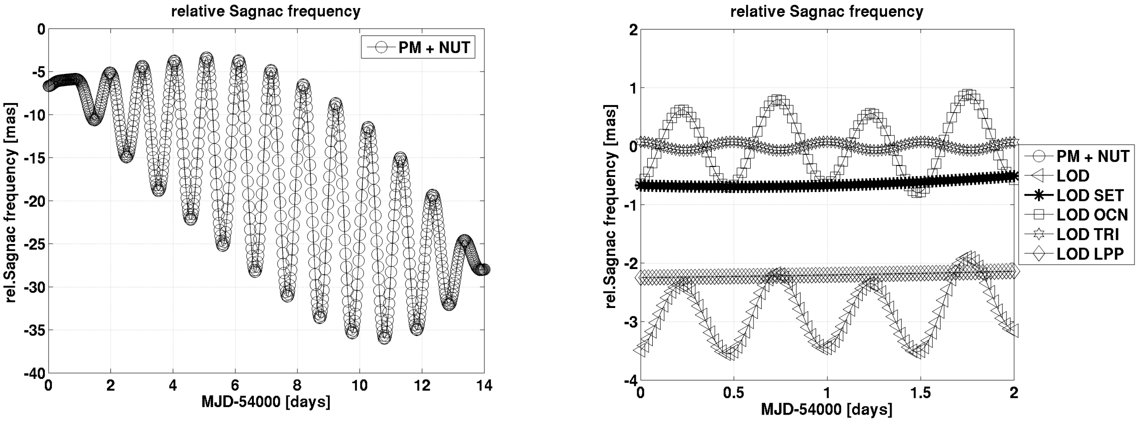


Figure 3 Computed relative Sagnac frequency variation from Earth orientation data and models in units of milliarcseconds (mas), from MJD 54000 to 54144. It is shown (*left panel*) for polar motion and precession-nutation (PM +NUT), (*right panel*) for LOD (total), for the solid Earth tides (LOD SET), for the ocean tides (LOD OCN), for the triaxiality (LOD TRI), and for the long period part (LOD LPP). The latter is mainly due to atmosphere angular momentum exchange.

4. Deformations due to exogenic and endogenic causes

Local effects are an important limitation in the accuracy of ring laser observables. Especially in the context of space geodesy, the study of such effects is of increasing importance. As the ring laser is coupled to the local Earth's surface, it is sensitive to deformations induced by exogenic and endogenic causes. Endogenic deformations are usually small or episodic in time and local in space (e.g. earthquakes). Exogenic deformations arise due to tidal forces and surface loading and traction (e.g. Earth body tides or tidal and non-tidal oceanic, atmospheric and hydrological loading) [Rautenberg et al., 1997].

The computation of the effect of the solid Earth tides in the relative Sagnac frequency is based on the model of [Mathews et al., 2002]. This model provides latitudinal displacements, which can be converted, through the Love numbers formalism, into latitudinal deflections, which are then transformed to the relative Sagnac frequency by equation 6.

5. Data analysis and results

Tiltmeter data

The tilmeter data (in north-south direction) was obtained for the time span September 22nd, 2006 to February 13th, 2007 with a temporal resolution of 30 minutes. Most of the signal seen in the tiltmeter data of Wettzell (see figure 4, left panel) contains the effect of the solid Earth tides, which has been derived from a model for north-south displacements [Mathews et al., 1997]. After removal of the tilt induced by the solid Earth tides, the effect of the ocean tides remain (see figure 4, right panel). The spectral amplitude and standard deviation (std) of the residuals has been obtained from forming a scalogram and averaging over the period band. The long-period part (larger than 2 days) has been filtered out after removing all known (modelled) signals.

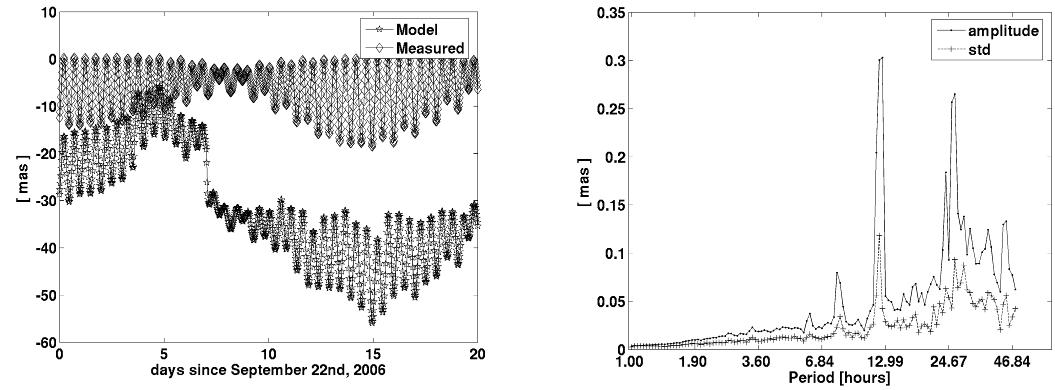
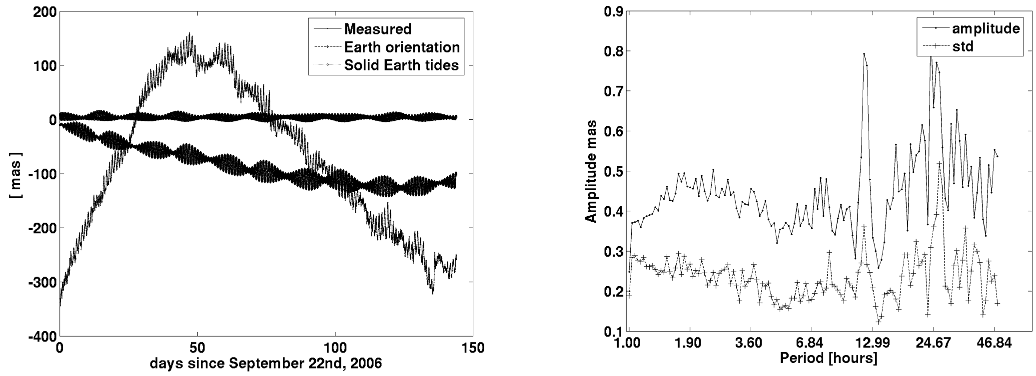


Figure 4 Computed (solid Earth tides model) and measured tilt in units of mas, from MJD 54000 to 54144. Only the 20 first days are shown for better visibility (*left panel*). The amplitude spectrum of the residual tiltmeter series (measured minus effect of solid Earth tides) is shown for periods between one and 48 hours (*right panel*). Sharp spectral peaks occur at 6, 8, 12, 24 and 25.8 hours in the residual tiltmeter series, and are mostly of ocean tidal origin.

Ring laser data

The ring laser data (relative Sagnac frequency) was also measured for the time span September 22nd, 2006 to February 13th, 2007 again with a temporal resolution of 30 minutes.



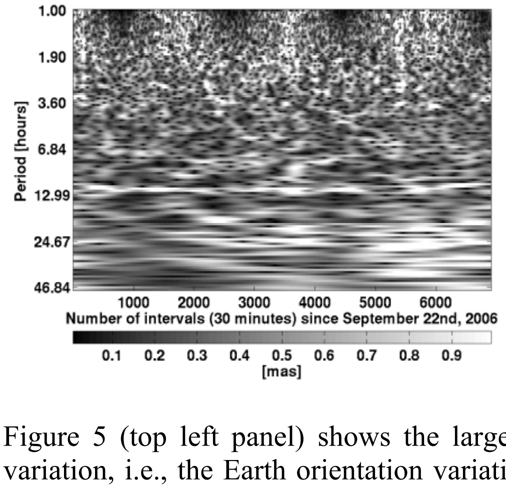


Figure 5 Computed (Earth orientation and solid Earth tides) and measured relative Sagnac frequency in units of mas, from MJD 54000 to 54144. The amplitude spectrum of the residual ring laser time series (measured minus effect of Earth orientation and solid Earth tides) is shown for periods between one and 48 hours. Residual spectral peaks occur at 12 (S2 wave) and 25.8 (O1 wave) hours and are still of unknown origin. The standard deviation in the O1 wave is of the level of 0.5 mas, while the one for the S2 wave is only 0.3 mas

Figure 5 (top left panel) shows the largest contributions to the relative Sagnac frequency variation, i.e., the Earth orientation variation and the effect of the solid Earth tides upon the local vertical. The top right panel (derived again from the scalogram, shown at the bottom left panel) brings to evidence a clear spectral peak, in the residual ring laser time series (measured minus Earth orientation minus solid Earth tides), for the S2 wave. Here, signals larger than two days have been filtered out. Besides, a regular increase in noise with a period of about one month can be detected in the scalogram (between one and three hours).

6. Love numbers and tilt factor

A north-south displacement d_{NS} of tidal origin is related through the tidal potential $V_n(r,\varphi,\lambda)$ by [Lambotte et al., 2006]:

$$d_{NS}(r,\varphi,\lambda) = \frac{l_n(r)}{g(r)} \cdot \frac{\partial V_n(r,\varphi,\lambda)}{\partial \varphi} \tag{7}$$

The north-south tilt sensed by a ring laser (only sensitive to deformation) is related through the tidal potential by:

$$t_{NS,RLG}(r,\varphi,\lambda) = \cot\varphi_0 \cdot \frac{\gamma_n(r)}{r \cdot g(r)} \cdot \frac{\partial V_n(r,\varphi,\lambda)}{\partial \varphi} \tag{8}$$

with the tilt factor $\gamma_n(r) = -h_n(r)$. Contrary to a ring laser, a tiltmeter also reacts to the induced attraction of the deformed Earth. For this reason, the tilt factor to which a tiltmeter is sensitive has the form $\gamma_n(r) = 1 + k_n(r) - h_n(r)$.

Therefore, the ratio of the degree-2 Love and Shida numbers (for an SNREI Earth model) when using the ring laser is given by:

$$\frac{h_2}{l_2} = -\frac{r \cdot t_{NS,RLG}}{\cot\varphi_0 \cdot d_{NS}} \tag{9}$$

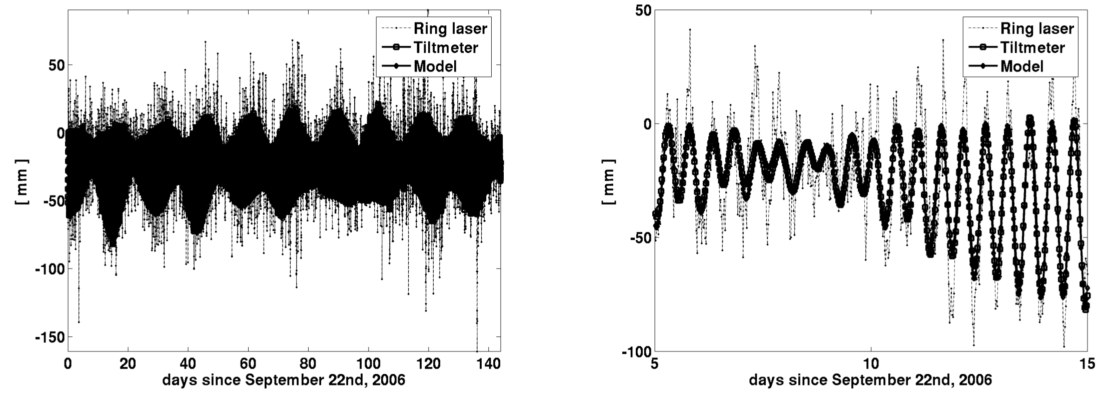


Figure 6 Measured (ring laser and tiltmeter) and modelled north-south displacement in units of mm, from MJD 54000 to 54144. The plot on the right shows a zoom for ten days since September 27th, 2006.

Figure 6 shows the north-south displacements in units of mm, derived from the ring laser data, the tiltmeter data, and a model [Mathews et al., 1997].

The respective factors, containing the Love numbers, have been varied from 0.5 to 1.5 w.r.t. to the nominal ones (for ring laser and tiltmeter), in order to minimize the standard deviation of the residuals (ring laser minus model, and tiltmeter minus model, see figure 7). If we consider the nominal Shida number $l_2 = 0.0847$ to be stable, we find optimal Love numbers: $h_2 = 0.6573$ and $k_2 = 0.3577$ (see figure 7).

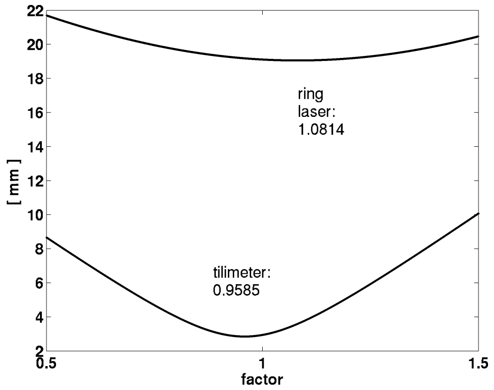


Figure 7 Minima for standard deviation of residuals (w.r.t. the model displacement in north-south direction) in units of mm. For the ring laser we obtain an optimum factor of 1.0814, while the optimum factor is 0.9585 for the tiltmeter. The minimum standard deviation for the ring laser is 19.1 mm, while the one for the tiltmeter is 2.9 mm.

7. Conclusions

At regular intervals of about one month, the noise of the “G” ring laser is considerably increased (~1 mas) in the frequency domain between one and three hours. The source of this noise is, for the moment being, unknown.

The ring laser “G” is able to monitor local tilts induced by local deformation. Although its sensitivity is one order of magnitude lower than that of the best tiltmeters, it was possible to estimate optimum Love numbers of degree 2, given a known nominal Shida number.

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NON TIDAL SIGNALS OF PLUMB LINE VARIATIONS OBSERVED WITH HELP OF THE LONG WATER-TUBE TILTMETER, IN GEODYNAMIC LABORATORY OF PAS IN KSIAZ

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Introduction

The observations of plumb lines variations are continued in Geodynamic Laboratory in Ksiaz since 1974. Up to 2002 we used a pair of quartz horizontal pendulums with photographic system of registration. In 2002 in the Geodynamic Laboratory in Ksiaz we started registration with long water-tubes tiltmeters. New tiltmeter system consists of two perpendicular tubes 65 and 83 meters long partially filled with water. The idea of measurements of the new tiltmeter is based on the principle of hydrostatic equilibrium. Luni-Solar forces as well as other large scale geodynamic phenomena generate asymmetric water level variations (increasing and decreasing) at the ends of the tubes. Water level variations are measured with the help of four interferometers installed at the ends of the tubes. Internal resolution of interference gauge is close to single nanometers of water level variation. It allows us to determine plumb line variations with internal resolution better than 10^{-2} millisecond of arc [mas] for several dozen meters long tube. High resolution of tiltmeter, lack of instrumental drift after application difference method for data reduction as well as other advantages open for us possibilities of investigations of non-tidal signals. Signals of plumb line variations consist of a periodical part of tidal origin as well as a non-periodical part or long period signals produced mainly by hydrological, meteorological, and geodynamical phenomena. Separation of tidal and non-tidal signals is relatively simple because we know exactly frequencies of tidal waves. In the case of water-tube observations we are able also to separate non-tidal signal from instrumental drift caused by effects of water evaporation and displacements of the tubes. To do that we subtract signals obtained from opposite ends of the tubes. Differentiation of signals causes double magnification of geodynamic signals as well as elimination of instrumental drift (Kaczorowski, 2006A). This circumstance helps us to investigate long-standing, non-tidal signals. With help of water-tube tiltmeter we observed five epochs of strong non-tidal signals. These phenomena took place in the autumn-winter and winter-spring transition periods as well as in the middle of summer (July 2006). Strong non-tidal signals of plumb line variations exceeded hundred of [mas]. We try to explain origin of such large effects. Specially suspected are local effects such as pressure or temperature variations in underground of laboratory.

Keywords: geodynamic, Earth tides, plumb line variations, non-tidal effects, tiltmeters.

1. **Observations of non-tidal signals with help of water tube tiltmeter**

Long standing non-tidal signals of irregular character was observed several times by quartz horizontal pendulums (Chojnicki T., Weiss J., 1981 and 1987). During thirty years of observations we irregularly observed epochs of unstable work of horizontal pendulums. Strong signals of non-tidal character occurred irregularly not only in transition periods between autumn-winter and winter-spring but also in the middle of summer or winter. Maximal values of non-tidal signal reach to hundred miliarcsecond of arc (a few tidal amplitudes of plumb line variations).

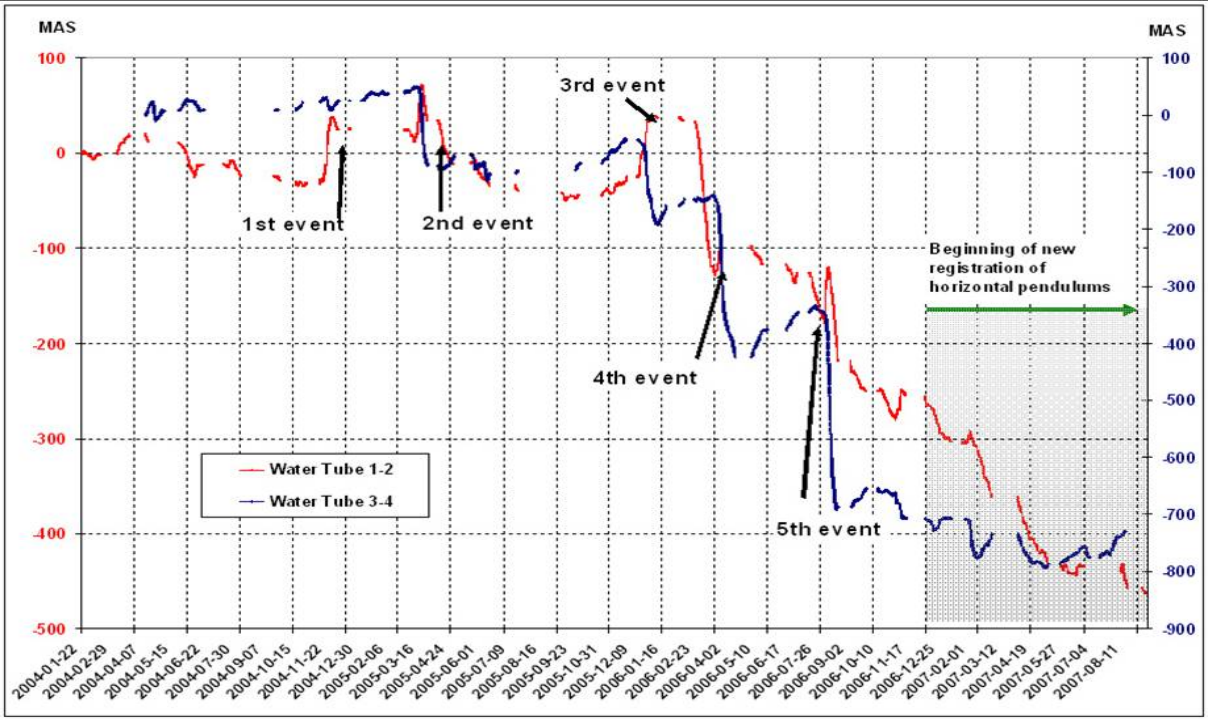


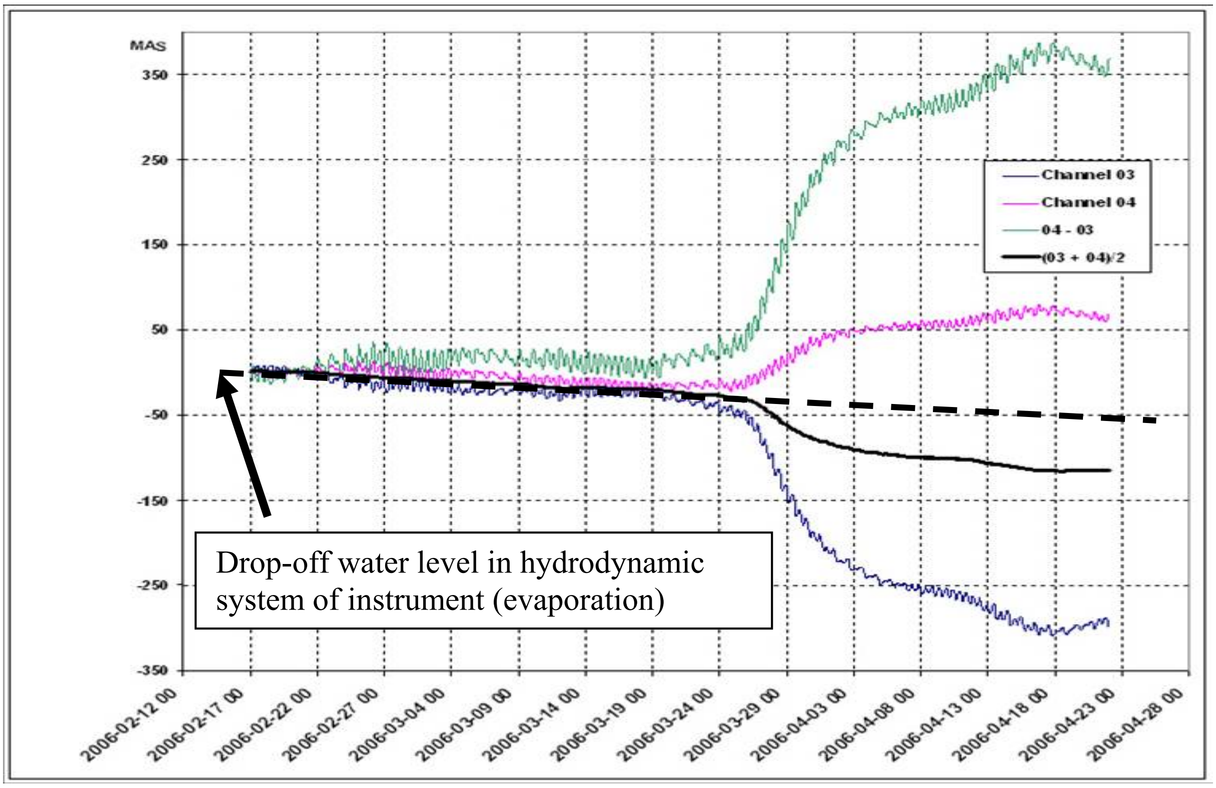
Fig.1. Non-tidal signal observed by long water-tube tiltmeter in period 2004-2007 in azimuth 58.6 [deg] (difference of signals 1-2) and in azimuth 148.6 [deg] (difference of signals 3-4)

Installation of the long water-tube tiltmeter in Ksiaz Geodynamic Laboratory opened in 2002 additional possibilities of investigating non-tidal irregular signals. Special features of new tiltmeter such as high sensitivity, possibility of elimination of instrumental drift by differential method of data reduction (Kaczorowski, 2006A) allowed us to initiate research on phenomena of strong, irregular signals of non-tidal origin. Application of differential method allowed us to eliminate from raw observations signals produced by effects of water condensation and evaporation from hydrodynamic system of tiltmeter (dotted lines on figures 2-5) as well as by displacements of the tubes (Kaczorowski, 2006A). Time series of plumb line variations were analyzed with help of program ETERNA 3.4 to eliminate tidal signals. After low pass filtration we obtained time series of non-periodical character. During years 2004-2007 we could observe five epochs of strong signals of plumb line variations (Fig.1.). These phenomena took place in the autumn-winter and winter-spring transition periods as well as in the middle of summer (July 2006). Therefore, we are able to exclude seasonal phenomena producing plumb line variations as reasons of large non-tidal signals. Very strong non-tidal signals were registered two times in 2006. Maximal signal exceeded 300 [mas]. Final azimuths of resultant plumb line variations differ less than -10 [deg] for all large events (Table 1). Directions of resultant azimuths are close to direction tectonic motions of plates observed by GPS permanent stations in Central Europe. Courses of strongest events are similar. The strongest effects occurred in azimuth close to the azimuth -31.4 of the tube named 3-4. For tube 3-4 moments of initiation of strong effects were preceded by few weeks long quiet intervals with tidal and evaporation effects only (Fig.2 and 3).

PERIODS OF STRONG SIGNALS AND DAYS OF DURATION			**AZIMUTHS AND AMPLITUDES OF PHENOMENA IN [MAS]**		**MEAN VELOCITY OF PLUMB LINE VARIATIONS [MAS]/DAY**		**RESULTANT AZIMUTH OF PLUMB LINE VARIATIONS**
From:	To:	Number of days	Tube 1-2 -121.4 (58^0.6)	Tube 3-4 -31.4 (148^0.6)	Tube 1-2	Tube 3-4	
17 November 2004	13 Decemb. 2004	26	60	No data	2.31	No data	No data
11 March 2005	28 March 2005	17	45	-140	2.64	-8.24	-13^0
16 December 2005	09 January 2006	23	56	-131	2.43	-5.70	-8^0
24 March 2006	14 April 2006	20	-156	-290	-7.80	-14.50	-3^0
28 July 2006	18 August 2006	20	-109	-350	-5.45	-17.50	-13^0
Since September 2007 strong signals were not been registered							

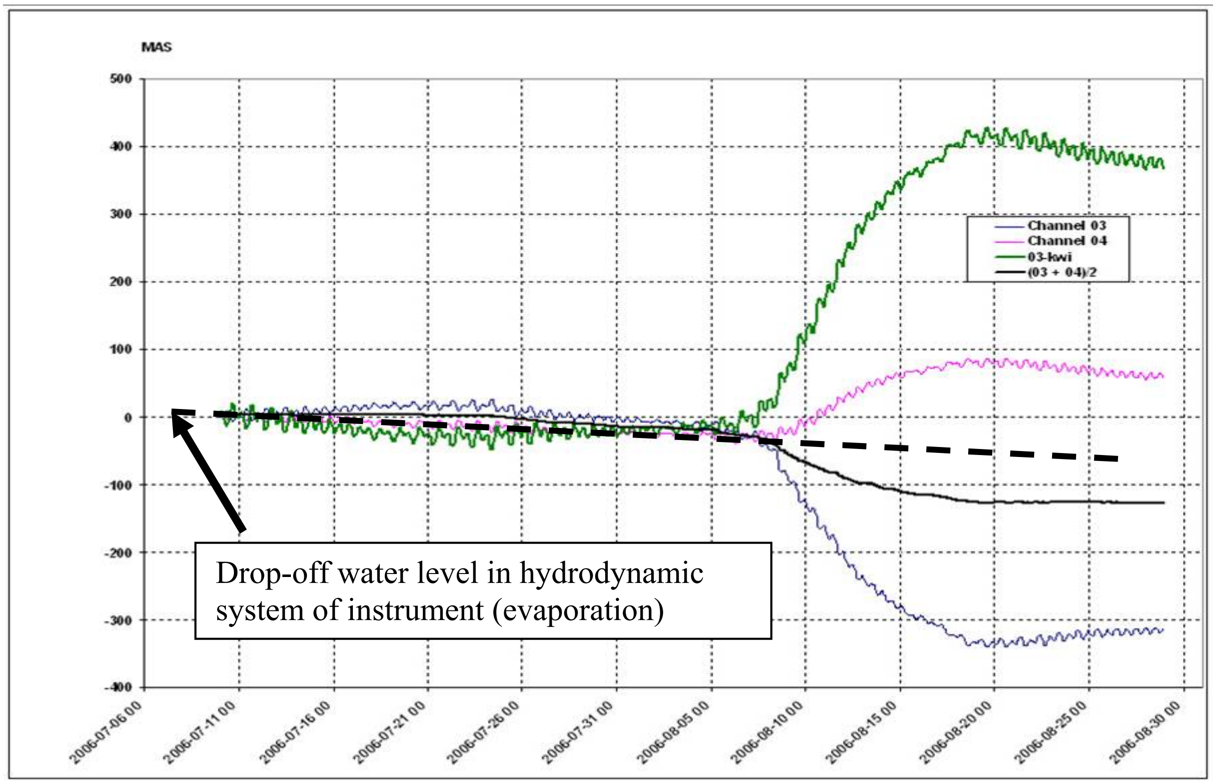
Table 1. The strongest non-tidal signals determined with difference method from channels 1-2 and 3-4 (1,2,3,4 numbers of channels) in period 2004-2007.

Next, main effects with systematic trends of tilts lasting dozen or so days begin. In azimuth -121.4 of the tube 1-2 plots of tilts during strong effects show us extremes (Fig.4 and 5), effects of tilts decrease and then again increase in this azimuth. This phenomenon is well visible on plot of non-tidal signal presented in space and registered during event from July 2006 (Fig.6). For azimuth -121.4 strong effects are not preceded by long intervals with tidal and evaporation effects only. In 2006 we resumed measurements with help of horizontal pendulums equipped with new system of electronic registration. We expect that this circumstance will allow us on verification of strong non-tidal signals detected by long water-tube tiltmeter. Detection of correlation between both tiltmeters should confirm additionally the thesis that observed large signals are geodynamic, not instrumental origin. In the case of positive verification we will study thirty year long series of pendulums observations to investigate strong non-tidal signals.



Drop-off water level in hydrodynamic system of instrument (evaporation)

Fig.2. Raw signals (tidal and non-tidal) observed by tube 03-04 in March 2006 (event 4th)



Drop-off water level in hydrodynamic system of instrument (evaporation)

Fig.3. Raw signals (tidal and non-tidal) observed by tube 03-04 in July 2006 (event 5th)

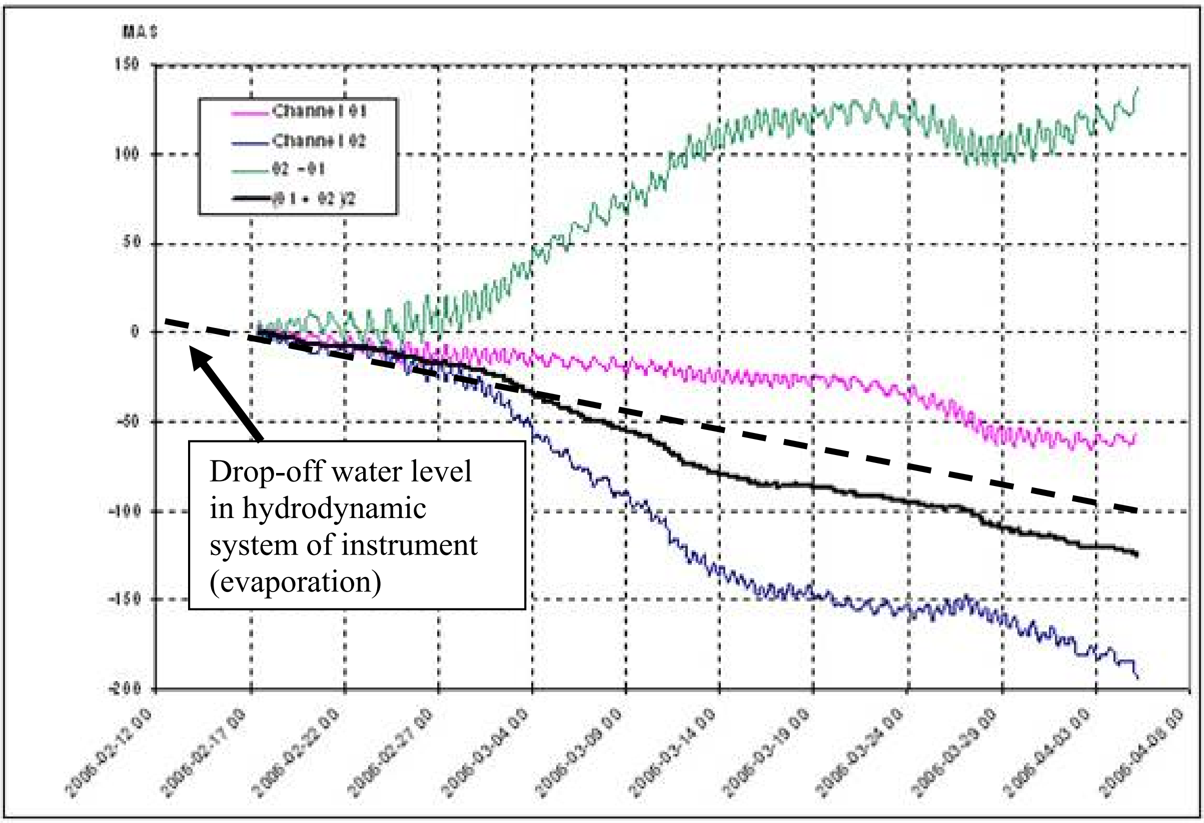


Fig.4. Raw signals (tidal and non-tidal) observed by tube 01-02 in March 2006 (event 4th)

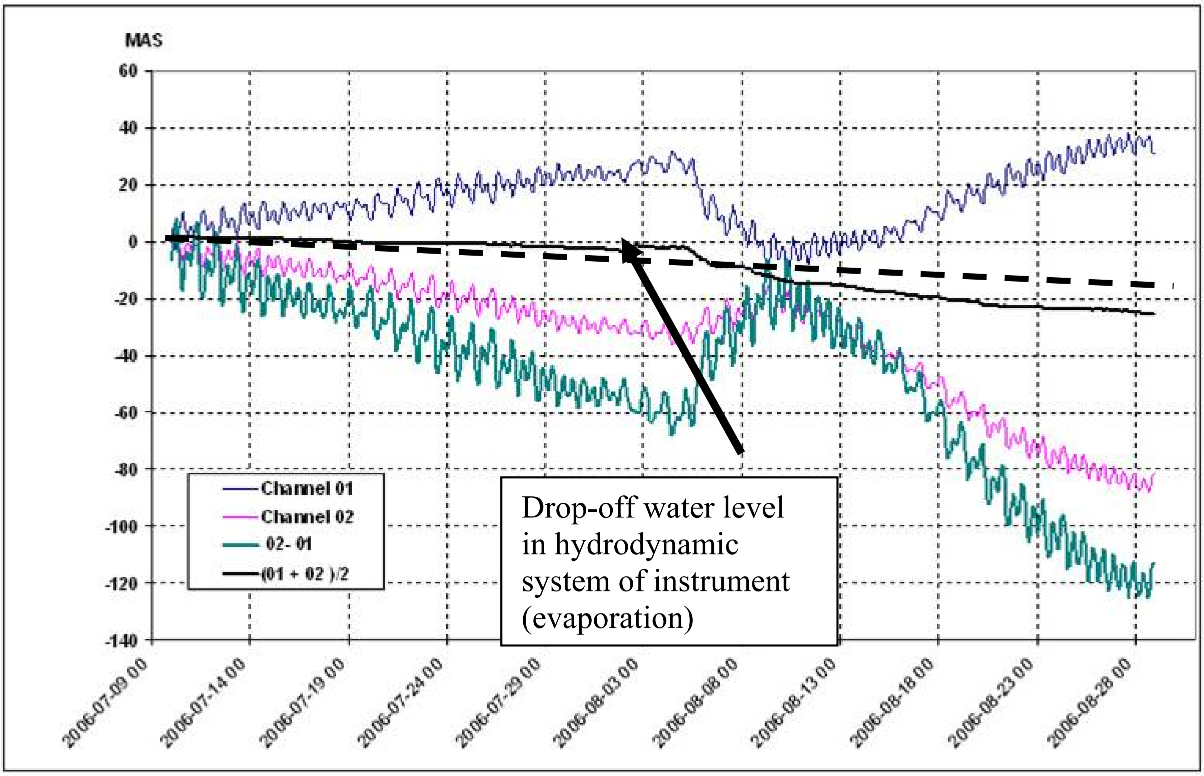


Fig.5. Raw signals (tidal and non-tidal) observed by tube 01-02 in July 2006 (event 5th)

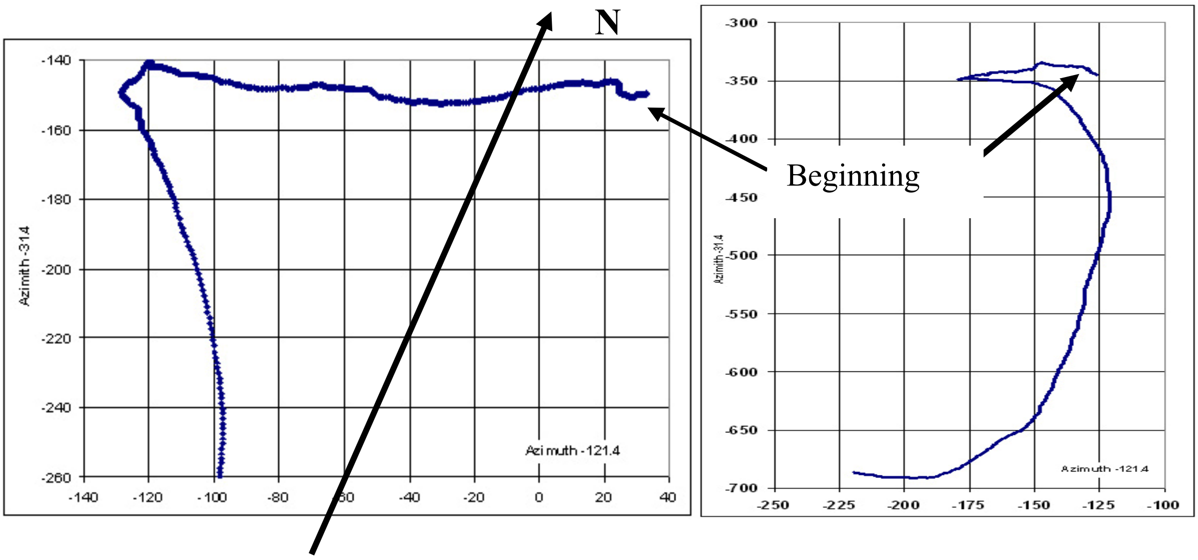


Fig.6. Non-tidal signals in space registered during event from March (left plot) and July (right plot) 2006

3. Possibility of generation of non-tidal signals by local effects such as pressure or temperature variations in gallery occupied by water-tube tiltmeter

Changes of pressure in underground can produce water level variations in tubes of tiltmeter by inverse barometric effect. Existence of horizontal component of pressure gradient along water-tubes is necessary condition to change water level. In the case when pressure changes produce asymmetric water level variations at the ends of the tubes, we can erroneously interpret these effects as non-tidal signals of plumb line variations. For 85 meters long tube and difference of pressure between ends of the tube equal to 4 10^{-3} [hPa] (pressure gradient is 5 10^{-5} [hPa/m]) inverse barometric effect produces signal of magnitude 100 [mas]. The gallery where tubes of tiltmeter were installed is open at one end and closed at the other. Surface of section of gallery is eighteen square meters. Horizontal component of pressure gradient appearing in gallery generates permanent motion of air along gallery from one side to opposite until pressure compensation. Because of large surface of section of gallery (18 m^2) horizontal component of pressure gradient vanishes in ten or less minutes. Experiment with artificial smog made in underground of laboratory show us horizontal velocity of air close to ¼ [m/sec]. Probably, we are able to expect great gradient of pressure 10^{-5} [hPa/m] but lasted maximally a few hours. Strong meteorological phenomena associated with rapid pressure variations initiate process of compensation of difference of pressure inside and outside of underground. During these events difference of pressure inside and outside underground can exceed 1 [hPa]. When process of compensation occurs variations of air pressure at both ends of the gallery (at both ends of the tubes) have the same trends - increasing or decreasing. Pressure variations of identical trends neither affect pressure gradient in gallery nor produce asymmetric signals of water level variations. Meteorological phenomena associated with effect of pressure compensation in underground lasted few days after which compensation trends became opposite. Therefore, explanation of a few weeks lasting systematic effects of water level variations by meteorological phenomena of pressure variations is improbable. Similarly to pressure variations the temperature variations in underground could also generate asymmetric signals of water level variations in water-tube tiltmeter. At the end of 2007 we installed system of continuous monitoring of temperature, pressure and humidity variations in underground of laboratory.

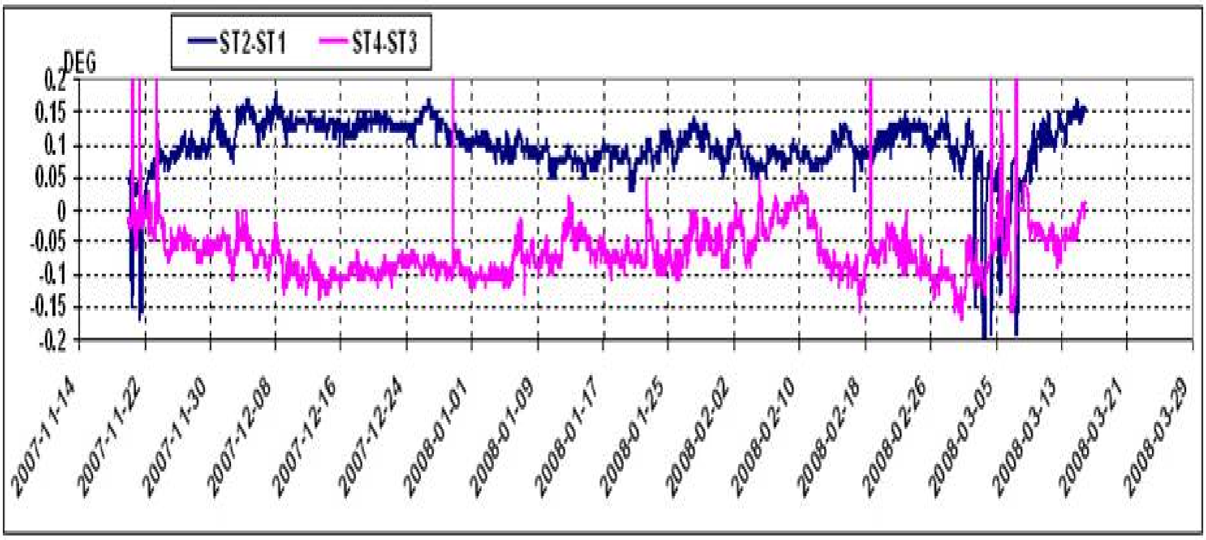


Fig.6. Plots of changes of differences of temperature occurring during winter period between ends of tubes

System consists of 26 sensors and their resolutions amount 0.01 [deg] for temperature, 0.01% for relative humidity and 0.1 [hPa]. Sensors were distributed among other at the ends of the tubes and in the room of horizontal pendulums. The results of measurements from October 2007 to March 2008 showed us that differences of temperature at the ends of the tube were close to 10^{-1} [deg]. Variations of temperature affected measurements of water-tube tiltmeter on several manners:

- Variations of volume of water in whole hydrodynamic system of tiltmeter produced by effect of thermal expansion of water.
- Variations of volume of the tubes due to thermal expansion.
- Variations of water density and height of equilibrium column of water.
- Variations of length of fasting screws in measuring platform of interferometer.

Effects of thermal variations of volume of water in hydrodynamic system of tiltmeter as well as variations of volume of tubes produce symmetric signal of water level variations and are reduced by the differential method of data reduction (Kaczorowski, 2006A). Temperature variations of density of water and height of water column above reflected lens as well as thermal variations of the length of fasting screws produce asymmetric signals in specific circumstance. To produce asymmetric signals of water level variations temperature changes ought to have opposite trends – increasing and simultaneously decreasing at the ends of the tubes. Situation when opposite ends of the gallery are simultaneously cooled and heated is improbable. Additional problem with explanation of strong non-tidal signals by temperature variations arrives if we take into attention small value of water thermal expansion (1.00004) and height of water column in interferometer (0.005 m). We evaluate thermal effect of variations of differences of temperature at the ends of the tubes between October 2007 and March 2008 on 10^{-7} [m]. This asymmetric signal of water level variations corresponds to 0.2 [mas] of plumb line variations.

4. Conclusions

The measurements from period 2004-2007 carried out by the long water-tube tiltmeter contained five epochs of strong (>100 [mas]) non-tidal signals. Strong non-tidal signals appeared in different months: November, March, December, and in the middle of summer.

Therefore, we are able to exclude any seasonal phenomena producing plumb line variations. Large, non-tidal signals registered by long water-tube cannot be simply explained by local effects such as pressure or temperature variations. Installed at the end of 2006 system of permanent monitoring of temperature, humidity, and pressure variations in underground of laboratory provides us information about possibility of generation of large, non-tidal signals by these changes. Magnitude of temperature variations (<0.1 deg) as well as horizontal gradient of temperature along the tubes (<<0.01 deg/m) observed between October 07 and March 08 exclude temperature variations as origin of large, non-tidal signals. It is also impossible to explain strong non-tidal signal by any pressure variations in underground of laboratory. There is difficult to show any mechanism of generation of lasting few weeks air pressure gradient in laboratory as well as to explain mechanism of simultaneous decreasing and increasing pressure at opposite ends of the gallery. In addition to observations of water-tube observations carried out with help of horizontal pendulums also contain strong non-tidal signals. Small size of pendulums, their construction and location in underground, exclude temperature and pressure effects as reason of strong non-tidal signals. On the basis of previous experiences we find that large non-tidal signals exceeding 100 [mas] are neither instrumental nor local origin. On account of magnitude of non-tidal signals we are able to exclude phenomena such as all known non-tidal loading and Newtonian effects of ocean (ocean tide effect in Ksiaz laboratory amount 1 mas for M2 wave) or meteorological origin.

In the case of meteorological effects explanation of large tilt signals by loading effects associated with horizontal gradient of pressure is difficult. There is too big difference between time of duration of large tilts effects (several weeks) and meteorological effects (several days). Moreover, the weather in March and July 2006 (4th and 5th events) was typically without anomaly. Because of technical problems about 35% of observations from period 2004-2007 are unavailable to be reduced by the differential method. Unavailable data were shown on (Fig.1) as empty spaces on plots of tilts. Therefore, evaluation of resultant tilts (-450 mas in azimuth 58.6 [deg] and -800 mas in azimuth 148.6 [deg]) (Fig.1) looks problematical. However, it is improbable that lost signals could compensate whole registered signals. During all large events in azimuths 58.6 [deg] plumb line variations were negative while in azimuth 148.6 [deg] they happened positive and negative. Taking into consideration variability of apparition of large tilt signals, four years long interval seems to be too short to answer the question of compensation of large tilt events. If we assume that for both components errors caused by lack of data are proportional to values of tilts, we are able to estimate azimuth of global resultant tilt equal to -2 [deg] for epoch 2004-2007. Azimuth of cumulated tilt associated with large tilt effects as well as azimuth of global resultant tilt are close to direction of tectonic motions in Central Europe. In this moment we incline to thesis that large non-tidal signals of plumb line variations are produced by recent crust movements.

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Tidal and long-period variations observed with tiltmeters, extensometers and well-sensor (Baikal rift, Talaya station).

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Abstract

The paper presents results of measurements with tidal tiltmeters and extensometers in Talaya underground gallery (51.64°N, 103.68°E, western part of Baikal rift) from 1985 to 2007. The station is located in a narrow mountain valley, near Tunka-Sayan fault zone, on the boundary between Siberian platform and Baikal rift zone. Tidal analyses of tilt and strain data allow to separate cavity and geological effect. Quartz horizontal pendulums, well-sensor, tube and laser extensometer (25 m) were used with EDAS and other digital systems. Well-sensor was situated in a 120 m borehole at the bottom of the valley (200 m from underground gallery). Water tidal signal was analyzed by strain-program. It is influenced by the valley orientation (40°N). Long-term tilt variation shows a 18 year loop followed by a westward drift. Strain observations along three directions allow to determine the main strain axes. Long-term behavior is compared with regional seismological data. Laser extensometers data was used for tidal analysis. Time variation of tidal amplitude and phase are presented. Finally, after removing local effects, the Love and Shida numbers computed from combined data are $h = 0.6077 \pm 0.0008$, $k = 0.3014 \pm 0.0004$ and $l = 0.0841 \pm 0.0001$.

Key words: quartz tiltmeters, tube and laser extensometers, borehole sensor, tidal parameters, long-period variation, Baikal rift, earthquakes.

1. Introduction

The measurements were made in the geodynamic observatory Talaya (coordinates 51.68° N, 103.65° E) located 7 km to the west of the Southwest extremity of the Baikal lake and 3 km to the South of the Main Sayan fault. Tilt and strain measurements are carried out in the 90m long underground gallery of the Talaya seismic station. The main gallery and the six perpendicular drifts have a cross section of 2x2 m^2. Water well is situated at 200 m from underground gallery. Results received at this station were published [Timofeev et al., 2000a, 2000b; Timofeev et al., 2006; Ducarme et al., 2008]. Tidal gravity measurements were performed in a special cellar. Observations with digital tidal gravimeter LCR-402

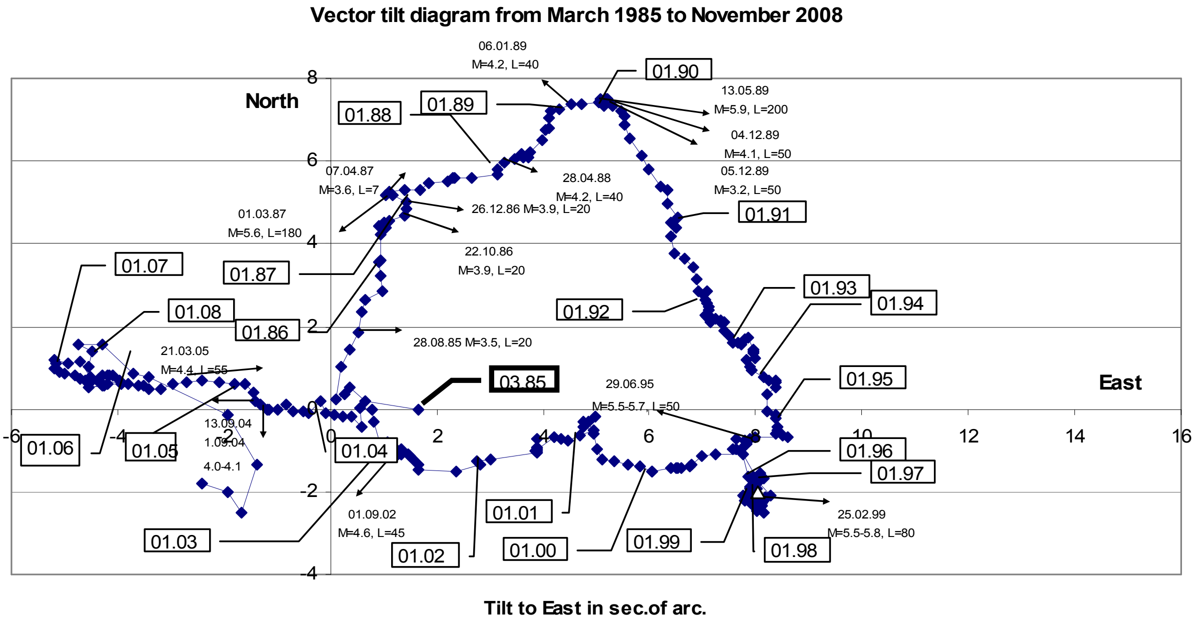


Figure 1. Tilt vector diagram from March 1985 to November 2008 (temp – one month), arrows – regional earthquakes, big arrow – last earthquake (1:35:31 27/08/2008, 51°.61, 104°.07, M = 6.1).

Table 1. Main strain orientation for Talaya station since 1989 deduced from extensometer data.

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Compression (1), $\varepsilon_1 \cdot 10^6$	0.0	6.9	6.7	2.7	7.8	9.0	11.3	12.8	12.9	13.3	12.5	13.0	14.8	15.3	15.7	15.4	16.0	17.5	18.2
Extension (2), $\varepsilon_2 \cdot 10^6$	0.0	-5.8	-0.4	0.6	-2.1	-4.3	-5.1	-3.0	-4.8	-3.3	-2.2	-3.2	-2.8	-3.9	-3.5	-3.1	-2.2	-2.1	-2.5
Vertical strain, $\varepsilon_3 \cdot 10^6$	0.0	-0.4	-2.1	-1.1	-1.8	-1.5	-2.1	-3.2	-2.7	-3.3	-3.5	-3.2	-4.0	-3.8	-4.1	-4.1	-4.6	-5.1	-5.2
Orientation (ε_1)	0.0	-45.1	22.5	18.5	41.8	43.4	42.2	45.1	46.6	50.9	49.8	48.5	48.1	47.8	48.7	51.3	50.4	47.6	46.7
Orientation (ε_2)	0.0	44.9	112.5	108.5	131.8	133.4	132.2	135.1	136.6	140.9	139.8	138.5	138.1	137.8	138.7	141.3	140.4	137.6	136.7
Volume strain, $\theta \cdot 10^6$	0.0	0.7	4.2	2.2	3.7	3.1	4.1	6.5	5.4	6.6	6.9	6.4	8.0	7.6	8.1	8.2	9.2	10.2	10.4
Shift strain, $\gamma \cdot 10^6$	0.0	12.7	-7.1	-2.1	-10.0	-13.3	-16.4	-15.8	-17.7	-16.6	-14.7	-16.2	-17.6	-19.2	-19.2	-16.5	-18.2	-19.6	-20.7

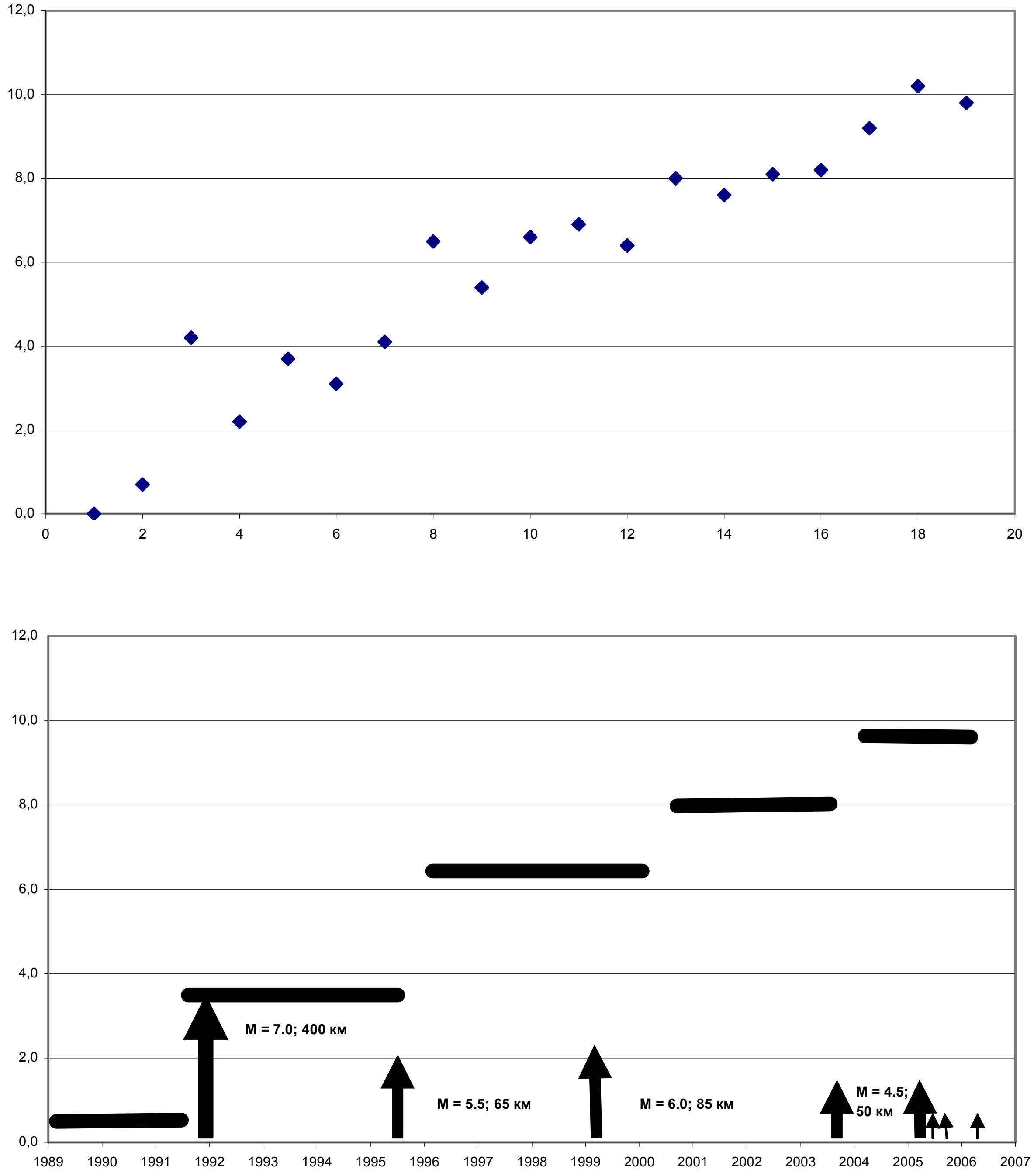


Figure 2. Volume strain variation (x10^6, 1989-2007 yy.) and earthquakes (see Table 1 and 2)

Table 2. List of earthquakes located 200km around Talaya station

Time and coordinates	Magnitude	Distance to epicenter (km) and magnitude range		
		0 < L < 50 M > 3.0	50 < L < 100 M > 4.5	100 < L < 200 M > 5.0
18h 27m 33.40s, 23/11/1994; 51.36°N, 104.14°E	3.0	50 km to SE		
04h 51m 14.80s, 20/02/1995; 51.28°N, 103.25°E	3.1	52 km to SW		
23h 02m 28,20s 29/06/1995; 51.71°N, 102.70°E	5.5-5.7		67 km to W	
05h 52m 31,40s 19/09/1996; 51.49°N, 103.95°E	3.0	30 km to S		
05h 00m 35,40s, 09/12/1997; 51.77°N, 103.39°E	3.9	20 km to W		
08h 05m 31,50s 10/02/1999; 51.64°N, 104.85°E	4.6		85km to E	
18h 58m 28,22s 25/02/1999; 51.63°N, 104.89°E	5.5-5.8		86 km to E	
19h 11m 07,00s 25/02/1999; 51.65°N, 104.80°E	5.3		86 km to E	
20h 24m 31,10s 25/02/1999; 51.58°N, 104.78°E	4.6		87 km to E	
00h 12m 28,30s 26/02/1999; 51.71°N, 104.79°E	4.5		86 km to E	
16h 28m 08,70s 31/05/2000; 51.71°N, 104.84°E	5.1		86 km to E	
07h 16m 31.60s 06/10/2001; 51,73 °N, 103,78° E	2.9	11 km to NE		
05h 19m 13.90s, 01/09/2002; 51,29°N, 103,33° E	4.6	49 km to SW		
02h 59m 56.00s, 17/09/2003; 51,75°N, 101,46° E	5.3			155 km to W
19h 55m 11.2s 23/02/2005 52.35°N, 101.59° E	5.3			160 km to NW
18h 04m 55.10s, 21/03/2005; 51,73°N, 104,40° E	4.5		52 km to E	
17h 05m 51.80s, 11/06/2005; 51,71°N, 103,94° E	3.4	22 km to E		
07h 34m 44.9s, 21/09/2005 51.72°N, 103.79° E	2.9	12 km to E		
01h 52m 17.3s, 18/02/2006 50.26°N, 105.37° E	5.0			200 km to SE
17h 15m 25.9s 06/03/2006 51.47°N, 103.82° E	3.1			25 km to SE
01h 35m 31s 27/08/2008 51.61°N, 104.07° E	6.1	25 km to E		

Table 3 : Tidal analysis results in NS component - from 05/1999 to 07/2003 by Program ANALYZE, version 3.40.

```
####################################################################
# Earth Tide Station Talay No. 1301 RUSSIA                         #
# BEMSE GS SB RAS                                                  #
# Institute of Geophysics SB RAS, Novosibirsk, Russia.             #
# 51.6810N  103.6440E  H550M                                       #
# Tilt NS                                                          #
# Calibration used.                                                #
####################################################################
 19990503...20030717    Recorded days in total: 379.208
 Tamura (1987) 1200 waves.

 Adjusted tidal parameters :
                          theor.
 from      to      wave    ampl. ampl.fac.    stdv. ph.lead    stdv.
 [cpd]     [cpd]           [mas]                      [deg]    [deg]

 0.501370 0.911390 Q1     0.3136   0.86573  0.15735   1.9780   7.7010
 0.911391 0.947991 O1     1.6379   0.88325  0.03022   8.7692   1.4487
 0.947992 0.981854 M1     0.1288   1.00597  0.25654  -0.6483  10.8175
 0.981855 0.998631 P1     0.7621   0.90122  0.09438   4.6423   4.4383
 0.998632 1.001369 S1     0.0180  30.26110  6.51725 156.7548   9.1498
 1.001370 1.004107 K1     2.3035   0.74189  0.03799   0.0298   2.1742
 1.004108 1.006845 PSI1   0.0180  18.17157  4.55190 174.9287  10.6114
 1.006846 1.023622 PHI1   0.0328   6.23346  2.14210-111.0360  14.5718
 1.023623 1.057485 J1     0.1288   0.75018  0.36217  27.2119  20.4192
 1.057486 1.470243 OO1    0.0705   1.03030  0.58887 -97.8232  24.1928
 1.470244 1.880264 2N2    0.2367   1.28854  0.17086  -4.7379   5.6319
 1.880265 1.914128 N2     1.4823   0.74683  0.03209   1.4791   1.8227
 1.914129 1.950419 M2     7.7420   0.69775  0.00650   7.3366   0.3950
 1.950420 1.984282 L2     0.2188   0.49144  0.24550 -78.0754  21.1776
 1.984283 2.002736 S2     3.6020   0.69779  0.01462   9.8926   0.8888
 2.002737 2.451943 K2     0.9792   0.35981  0.05061  22.2757   5.9668
 2.451944 7.000000 M3M6   0.0944   0.60844  0.44718   0.6115  31.1835

 Standard deviation on unit weight:           2.736
```

Table 4 : Tidal analysis results in EW component - from 05/1999 to 01/2000 by Program ANALYZE, version 3.40.

```
############################################################################
# Earth Tide Station Talay No. 1301 RUSSIA                                 #
# BEMSE GS SB RAS                                                          #
# Institute of Geophysics SB RAS, Novosibirsk, Russia.                     #
# 51.6810N  103.6440E  H550M                                               #
# Tilt EW                                                                  #
# Calibration used.                                                        #
############################################################################
19990510...20000124     7 blocks. Recorded days in total:    138.083
Hartmann+Wenzel (1995) 434 waves.

adjusted tidal parameters :
                        theor.
from      to      wave   ampl.   ampl.fac.  stdv.  ph. lead   stdv.
[cpd]     [cpd]          [mas]                     [deg]      [deg]

0.501370 0.911390 Q1      0.9783   0.72995  0.18116 -23.9031  13.0968
0.911391 0.947991 O1      5.1095   0.56303  0.04368   2.7758   4.0890
0.947992 0.981854 M1      0.4016   1.32675  0.67244  66.3159  26.6897
0.981855 1.023622 P1K1    7.1829   0.64644  0.02569   1.3367   2.0947
1.023623 1.057485 J1      0.4018   0.75163  0.46944   9.0651  32.9707
1.057486 1.470243 OO1     0.2198   0.37185  1.42737  63.9568 201.6397
1.470244 1.880264 2N2     0.2999   1.03288  0.20150  15.7361  10.2850
1.880265 1.914128 N2      1.8778   0.77600  0.04911  -1.6245   3.3346
1.914129 1.950419 M2      9.8077   0.70702  0.01102  -1.6375   0.8221
1.950420 1.984282 L2      0.2772   0.29072  0.43553  46.8611  78.8911
1.984283 2.451943 S2K2    4.5626   0.68071  0.02592  -2.5299   2.0063
2.451944 7.000000 M3M60.1196   0.23136  0.52132  41.1160 118.6749

Standard deviation on unit weight:            1.793   mas
```

agree well with the DDW99 (Dehant et al., 1999) model. The objective of our study is to estimate current surface deformation in the south-west part of Baikal rift using local deformation measurement. The last data processing and tidal analysis of these long series are described in this paper.

2. Tilt and strain long-term variations

The long series of quartz tiltmeter data have been obtained in the underground gallery of Talaya seismic station starting from 1985 until present day. Long-term tilt variation shows a 18 year loop followed by a linear drift to the West (Figure 1). Long series of extensometers data have been observed in the underground gallery starting from 1990 until present day. The equipment consists primarily of two short quartz tube extensometers and an invar rod strainmeter with induction sensors (Timofeev et al., 2000b). Later on a laser extensometer with two 25m orthogonal legs was also installed. This set of extensometers was installed in different drifts and directions (-24° N, -22.5° N, 0° N, 90° N, 66° N), as we need at least three different directions to calculate the variations of main strain axes for long term study of the tectonic activity (Table 1, Figure 2). Long-term tilt and strain variation reflects the regional seismic activity (Table 2).

3. Earth Tide Analysis of Tilt Data

The earth tide analysis of the quartz tiltmeters data set 1988-1998 has been carried out not only with method VEN66 (Venedikov, 1966) using the CTE550 tidal potential and filtering on 48 hours blocks but also with ETERNA 3.4 (Wenzel, 1996) using the Tamura tidal potential and Pertsev numerical filters (Gridnev et al., 1993, Timofeev et al., 2000a). The adjusted tidal parameters are given in Table 3 for North-South component and in Table 4 for East-West component. The standard deviation of unit weight for different components and for different periods reaches 2 to 2.5 mas. The results of tidal analysis by the two methods are similar in amplitude and in phase. The discrepancies are due to the different filtering techniques interfering with the gaps.

Slight changes are observed between successive partial analysis. They can be due to temporal variations of the calibration factor and temporal variations of the signal cable impedance. This last effect is probably responsible of the large S_1. Tidal analysis of barometric pressure shows a diffuse effect in the diurnal band with a maximum at S_1 frequency and only one peak on S_2 in the semi-diurnal band. Local cavity effect (Harrison, 1976) is perturbing M_2 (NS) phase lag result (9°) but this effect is absent on EW results. Tilt-strain coupling effect for M_2 wave is absent in EW direction at Talaya.

4. Strain difference

The best results for the laser system have been observed for differential strain as in this case we obtain the best elimination of the air pressure influence

(Table 5). We used for tidal analyses of strain difference between two orthogonal directions the version “0” (gravity) of the ETERNA analysis programs with a convenient renormalisation to convert it to strain evaluation i.e. potential divided by g (absolute gravity) and by R (Earth radius at the observation point).

As known [Melchior, 1976, Timofeev et al., 2000b] for strain in two directions of azimuth *a1* and *a2* we have:

$$e_{d1} = \cos^2 a1 \cdot e_{\theta\theta} + \sin^2 a1 \cdot e_{\lambda\lambda} + \cos a1 \cdot \sin a1 \cdot e_{\theta\lambda},$$

$$e_{d2} = \cos^2 a2 \cdot e_{\theta\theta} + \sin^2 a2 \cdot e_{\lambda\lambda} + \cos a2 \cdot \sin a2 \cdot e_{\theta\lambda},$$

We have for strain difference:

$$\Delta e = e_{d1} - e_{d2}$$

$$= e_{\theta\theta} \cdot (\cos^2 a1 - \cos^2 a2) + e_{\lambda\lambda} \cdot (\sin^2 a1 - \sin^2 a2) - e_{\theta\lambda,} \cdot (\cos a1 \cdot \sin a1 - \cos a2 \cdot \sin a2)$$

When the first direction is perpendicular to the second one:

$a2 = a1 + 90°$

and we can use only one angle $a1 = \alpha$ to express the strain difference:

$$\Delta e = (e_{\theta\theta} - e_{\lambda\lambda})(\cos^2\alpha - \sin^2\alpha) - 2\, e_{\theta\lambda,} \cdot \sin\alpha \cdot \cos\alpha$$
$$= (e_{\theta\theta} - e_{\lambda\lambda}).\ \cos 2\alpha + e_{\theta\lambda,} \cdot \sin 2\alpha$$

For the different tidal waves we have:

Sectorial waves –

$$e_{\theta\theta} = [h + 2((1-2\sin^2\theta)/\sin^2\theta)\cdot l]\cdot J_2/a\cdot g$$

$$e_{\lambda\lambda} = [h - 2((1+\sin^2\theta)/\sin^2\theta)\cdot l]\cdot J_2/a\cdot g$$

$$e_{\theta\lambda} = 4l[(\cos\theta / \sin^2\theta)\cdot \tan 2H]\cdot J_2/a\cdot g$$

Tesseral waves -

$$e_{\theta\theta} = (h - 4l)\cdot T_2/a\cdot g$$

$$e_{\lambda\lambda} = (h - 2l)\cdot T_2/a\cdot g$$

$$e_{\theta\lambda} = -2l\cdot(tgH/\cos\theta)\cdot T_2/a\cdot g$$

where h and l are tidal number, J_2 and T_2 - tidal potential, *a* - radius of Earth, *g* – gravity,

θ - colatitude, *H* - hour’s angle.

Using these formulas for computing the strain difference, we get

.

Table 5 (a). Tidal analysis of differential laser strain data - from 01/1995 to 11/2003 by ETERNA 3.4 (gravity version).

Wave	Ampl. Observ (nstr)	Ampl. Error (nstr)	Ampl. Factor Obser.	Ampl. Factor Error	Phase Observ	Phase error
O1	2.950	0.018	0.1952	0.0012	-60°.57	0°.07
K1	3.830	0.017	0.1777	0.0008	-72°.30	0°.05
N2	1.702	0.016	0.6518	0.0061	66°.48	0°.35
M2	9.970	0.017	0.6901	0.0012	65°.36	0°.07
S2	5.008	0.016	0.7451	0.0024	68°.08	0°.14

Table 5 (b). Azimuth, phase, coefficient and Love number.

```
AZ    phase d    F1/l      l(O1)  phase sd   F2/l      l(M2)
-22.75    -52.37   2.29587 0.08502     44.66   8.28210 0.08332
-23.00    -52.85   2.30061 0.08485     45.17   8.27999 0.08334
-23.25    -53.33   2.30534 0.08467     45.67   8.27789 0.08336
-23.50    -53.81   2.31005 0.08450     46.17   8.27578 0.08339
-23.75    -54.29   2.31475 0.08433     46.67   8.27368 0.08341
-24.00    -54.76   2.31944 0.08416     47.17   8.27158 0.08343
-24.25    -55.23   2.32410 0.08399     47.67   8.26948 0.08345
-24.50    -55.71   2.32875 0.08382     48.17   8.26739 0.08347
-24.75    -56.17   2.33337 0.08366     48.67   8.26530 0.08349
-25.00    -56.64   2.33798 0.08349     49.18   8.26322 0.08351
-25.25    -57.11   2.34256 0.08333     49.68   8.26114 0.08353
-25.50    -57.57   2.34711 0.08317     50.18   8.25907 0.08355
-25.75    -58.03   2.35164 0.08301     50.68   8.25701 0.08358
-26.00    -58.49   2.35615 0.08285     51.19   8.25495 0.08360
-26.25    -58.95   2.36062 0.08269     51.69   8.25290 0.08362
-26.50    -59.41   2.36507 0.08253     52.19   8.25087 0.08364
-26.75    -59.86   2.36948 0.08238     52.70   8.24884 0.08366
-27.00    -60.32   2.37387 0.08223     53.20   8.24682 0.08368
-27.25    -60.77   2.37822 0.08208     53.71   8.24481 0.08370
-27.50    -61.22   2.38253 0.08193     54.21   8.24282 0.08372
-27.75    -61.67   2.38682 0.08178     54.72   8.24083 0.08374
-28.00    -62.11   2.39106 0.08164     55.22   8.23886 0.08376
-28.25    -62.56   2.39527 0.08149     55.73   8.23691 0.08378
-28.50    -63.00   2.39944 0.08135     56.23   8.23496 0.08380
-28.75    -63.44   2.40357 0.08121     56.74   8.23303 0.08382
-29.00    -63.88   2.40766 0.08107     57.24   8.23112 0.08384
-29.25    -64.32   2.41171 0.08094     57.75   8.22922 0.08386
-29.50    -64.76   2.41571 0.08080     58.26   8.22734 0.08388
-29.75    -65.20   2.41968 0.08067     58.76   8.22548 0.08390
-30.00    -65.63   2.42360 0.08054     59.27   8.22363 0.08391
-30.25    -66.06   2.42747 0.08041     59.78   8.22180 0.08393
-30.50    -66.50   2.43129 0.08029     60.29   8.21999 0.08395
-30.75    -66.93   2.43507 0.08016     60.79   8.21820 0.08397
-31.00    -67.36   2.43880 0.08004     61.30   8.21643 0.08399
-31.25    -67.78   2.44248 0.07992     61.81   8.21468 0.08401
-31.50    -68.21   2.44611 0.07980     62.32   8.21295 0.08402
-31.75    -68.64   2.44969 0.07968     62.83   8.21124 0.08404
-32.00    -69.06   2.45322 0.07957     63.34   8.20955 0.08406
-32.25    -69.48   2.45670 0.07946     63.85   8.20789 0.08408
-32.50    -69.91   2.46012 0.07935     64.35   8.20625 0.08409
```

```
-32.75     -70.33    2.46349 0.07924      64.86     8.20463 0.08411
-33.00     -70.75    2.46680 0.07913      65.37     8.20304 0.08412
-33.25     -71.16    2.47005 0.07903      65.88     8.20147 0.08414
-33.50     -71.58    2.47325 0.07892      66.39     8.19992 0.08416
-33.75     -72.00    2.47640 0.07882      66.90     8.19841 0.08417
-34.00     -72.41    2.47948 0.07873      67.41     8.19691 0.08419
-34.25     -72.83    2.48250 0.07863      67.92     8.19545 0.08420
-34.50     -73.24    2.48547 0.07854      68.44     8.19401 0.08422
-34.75     -73.65    2.48837 0.07844      68.95     8.19260 0.08423
-35.00     -74.06    2.49122 0.07836      69.46     8.19121 0.08425
```

Table 6. Tidal analysis of water well data by “Strain version” (130°N).
Period: from 5h 11/06/2007 to 18h 17/01/2008.

```
Azimuth from north direction     130.0 deg
Adjusted tidal parameters :
from   to wave   ampl. signal/ ampl.fac.    stdv. phase lead    stdv.
          [ nstr   ]  noise                   [deg]     [deg]

 286  428 Q1       0.041     4.1   0.03590  0.00884  136.7197    0.5069
 429  488 O1       0.347    32.9   0.05790  0.00176   47.6414    0.1008
 489  537 M1       0.058     7.0   0.12384  0.01773   60.0412    1.0166
 538  592 P1SK1 0.383    27.1   0.04548  0.00168   68.3259    0.0983
 593  634 J1       0.033     3.4   0.07114  0.02110   76.8102    1.2088
 635  736 OO1      0.031     5.1   0.11973  0.02357  126.3101    1.3471
 737  839 2N2      0.025     2.7   0.12430  0.04596  -14.3450    2.6347
 840  890 N2       0.125    10.7   0.09842  0.00921   14.4761    0.5276
 891  947 M2       0.676    54.6   0.10164  0.00186    2.4094    0.1066
 948  987 L2       0.006     0.5   0.03168  0.06786  -12.3562    3.8808
 988 1121 S2K2  0.299    30.8   0.09677  0.00314   14.3476    0.1764
1122 1214 M3     0.016     1.3   0.52895  0.39395  -11.0200   22.5727
Standard deviation of weight unit:     0.333
degree of freedom:                     1578
Adjusted meteorological or hydrological parameters:
no. regr.coeff.       stdv.  parameter   unit
  1    2.36523     0.10444            mm / KPa
```

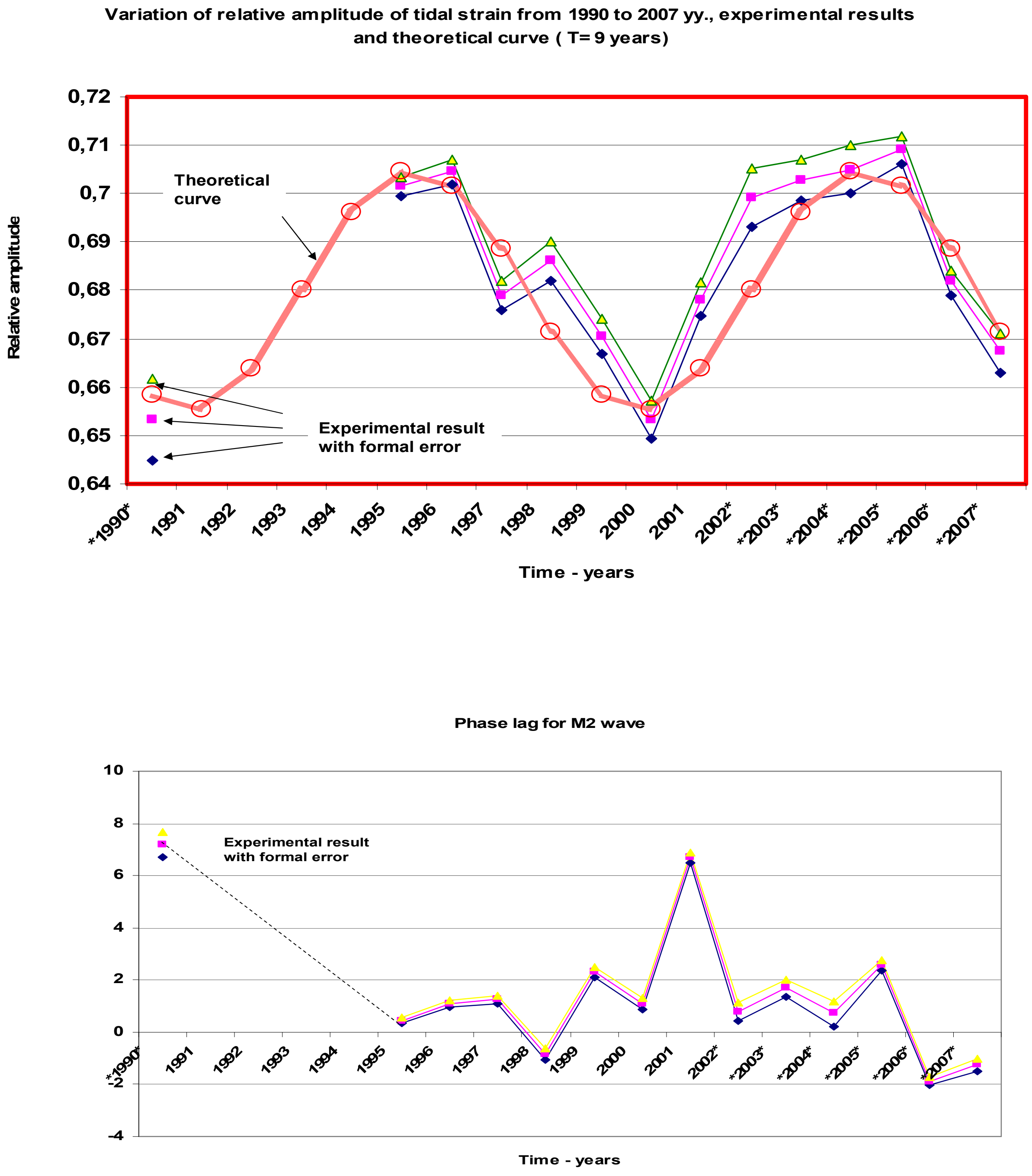


Figure 3. Tidal amplitude and phase variation (1990-2007 yy.) by laser extensometer consecutive annual analyses (M2, differential strain, annual analysis results).

Top - Relative tidal amplitude and theoretical curve: $f = A \sin(\omega t + \varphi)$, where A = 0.025 (3.6% of mean amplitude), $\omega = 2\pi/T$, T = 9 years and t – time.

Bottom - phase variation by laser extensometer annual data in degrees (difference from mean value).

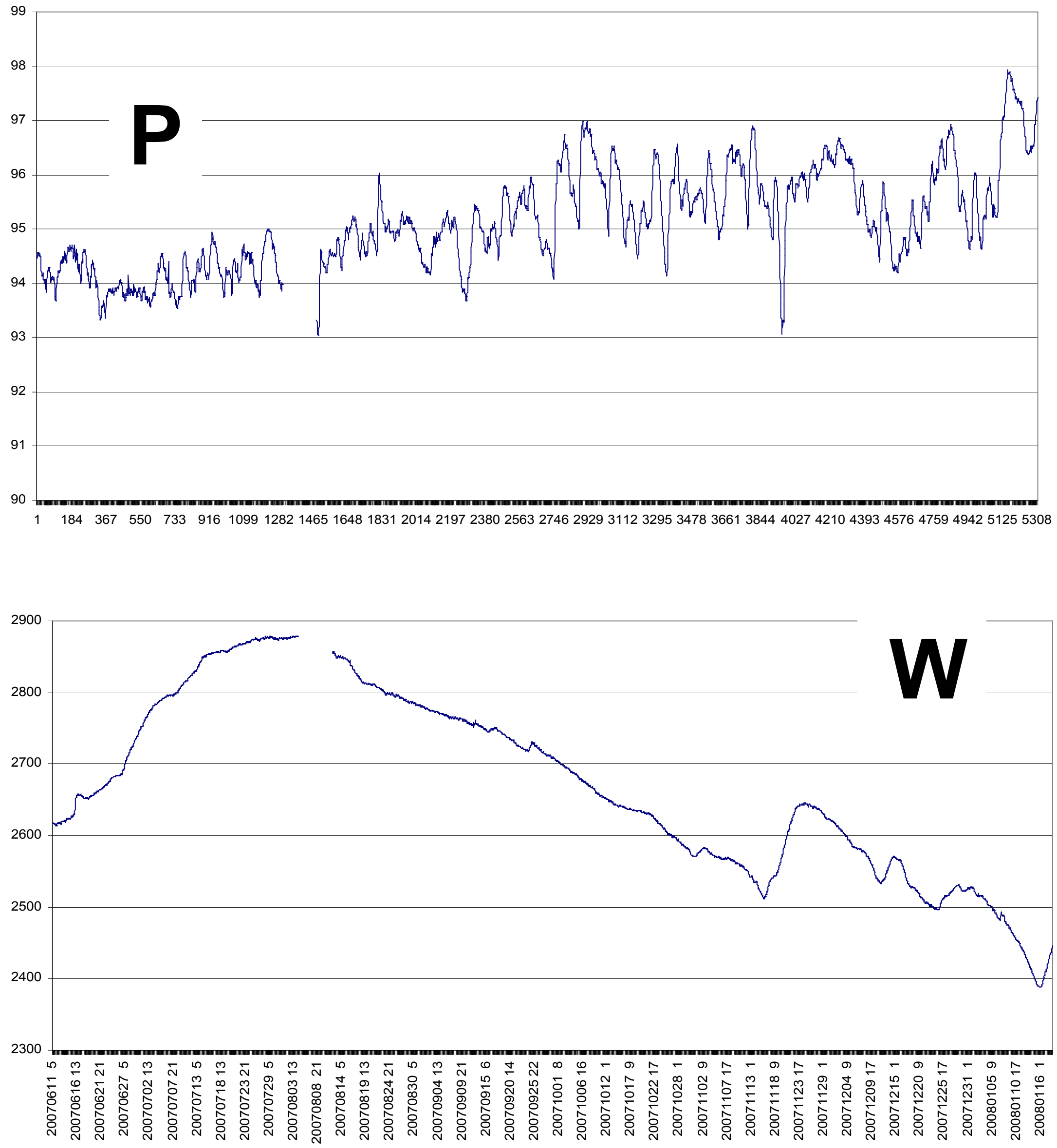
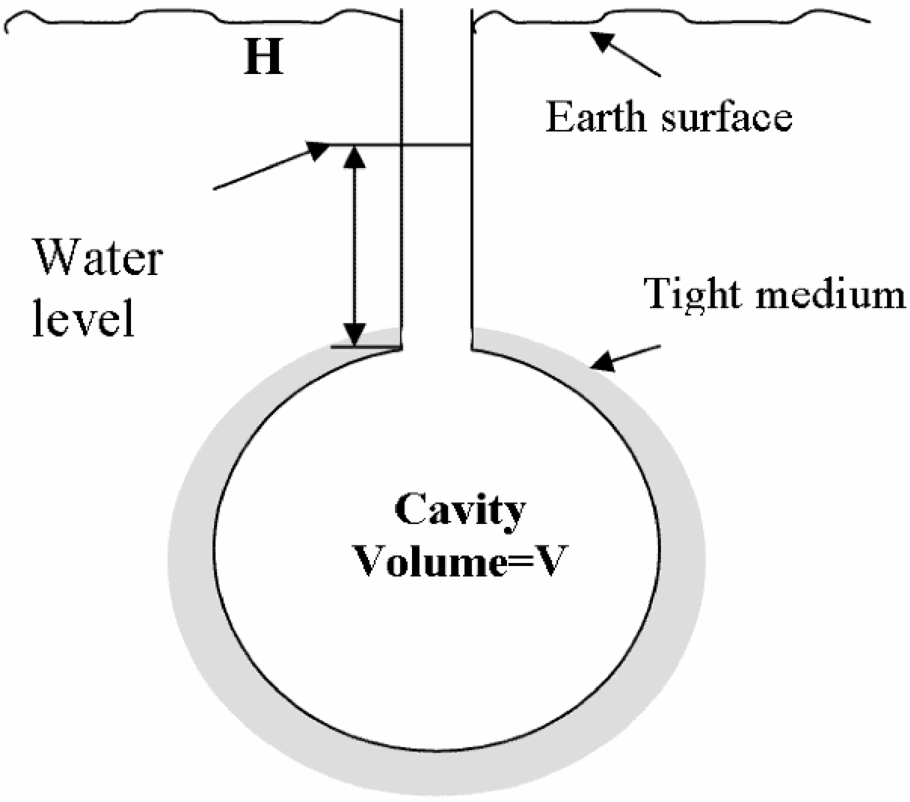


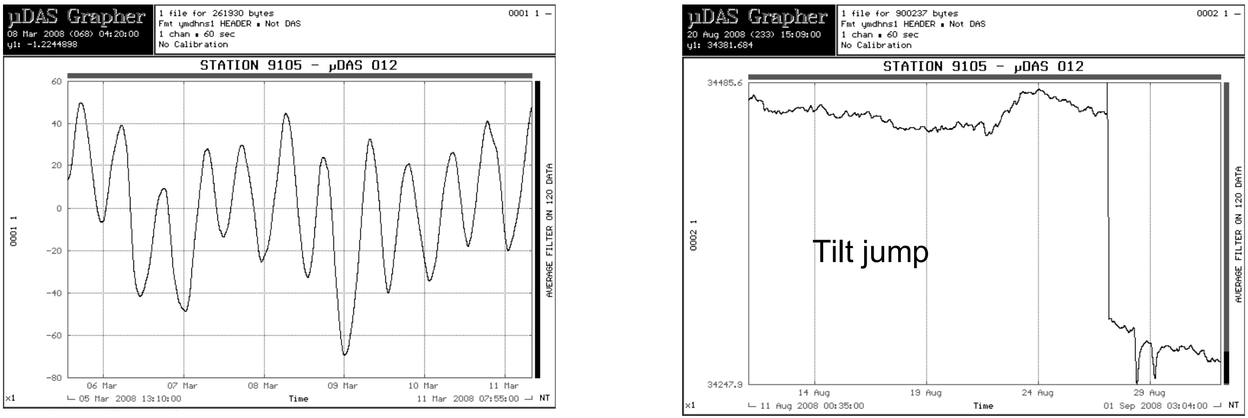
Figure 4. Variation of air pressure (P) and water level (W) for Talaya well from 5h 11/06/2007 to 18h 17/01/2008. (P in KPa and W in mm).



¶

¶

Figure 5. Finite cavity model of well.



Tilt NS variation (March 2008)

Strain jump Δ ≈ $0.9 \cdot 10^{-6}$
K = $5 \cdot 10^{10}$ Pa, Stress 0.45 Bar

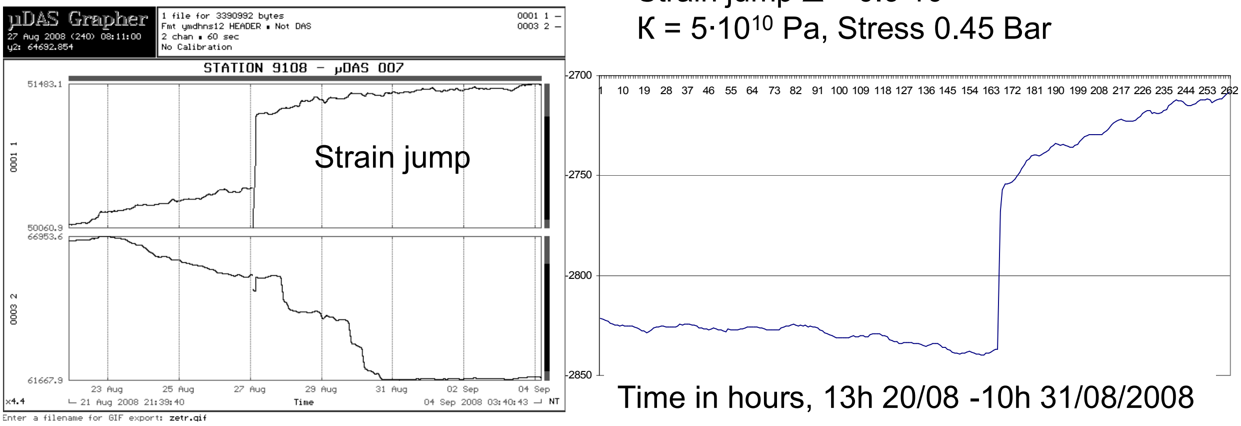
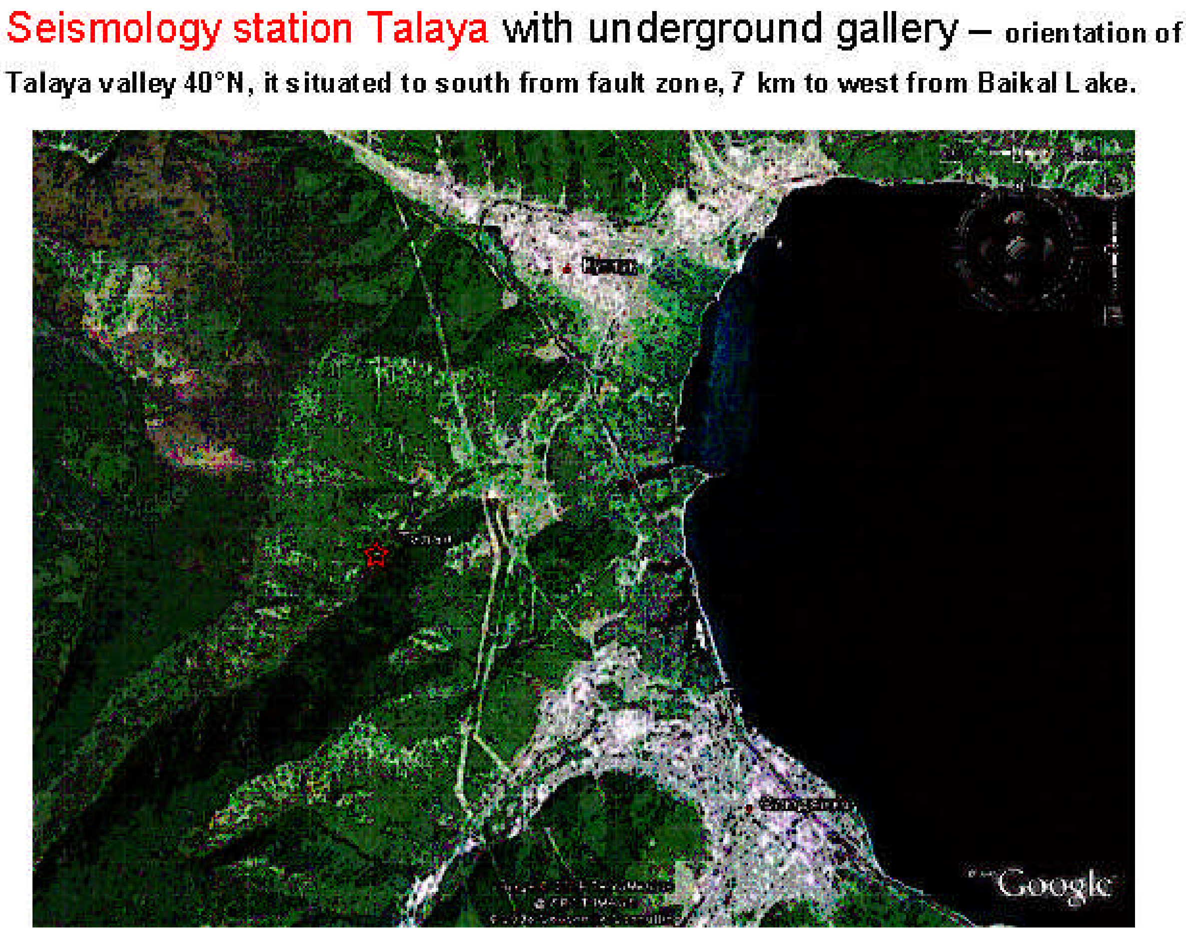


Figure 6. Tidal variation and earthquake jump on 27/08/2008
Top: tilt normal curve(left) and reaction to earthquake (right),
Bottom: strain (left) and water level variations (right).



Seismology station Talaya with underground gallery – orientation of Talaya valley 40°N, it situated to south from fault zone, 7 km to west from Baikal Lake.

Figure 7: Talaya station (star) and Baikal Lake.

Sectorial waves

$$\Delta e_2 = \cos 2\alpha \cdot (e_{\theta\theta} - e_{\lambda\lambda}) + \sin 2\alpha \cdot e_{\theta\lambda} =$$

$$\{[2l\cdot \cos 2\alpha \cdot(2 - \sin^2\theta) / \sin^2\theta)] + [4l\cdot \sin 2\alpha \cdot (\cos\theta / \sin^2\theta)\cdot \tan 2H]\}\cdot J_2/a\cdot g$$

Tesseral waves

$$\Delta e_1 = \cos 2\alpha \cdot (e_{\theta\theta} - e_{\lambda\lambda}) + \sin 2\alpha \cdot e_{\theta\lambda} =\{(-2l\cdot \cos 2\alpha) - [2l\cdot \sin 2\alpha \cdot(tgH/\cos\theta)]\}\cdot T_2 /a\cdot g$$

After the calculation we obtain the theoretical values for amplitude factor and phase :

Sectorial waves

Amplitude factor $F_2 = (2l /\sin^2\theta)\cdot\sqrt{}[(2\cos\theta \cdot\sin 2\alpha)^2 + \cos^2 2\alpha\cdot(2 - \sin^2\theta)^2]$

Phase $\Delta\varphi_2 =$ -arctg$[2\tan 2\alpha.\cos\theta /(2 - \sin^2\theta)]$

Tesseral waves

Amplitude factor $F_1 =[2l/(\cos\theta)]\cdot\sqrt{}(\cos^2 2\alpha\cdot\cos^2\theta +\sin^2 2\alpha)$

Phase $\Delta\varphi_1 =$ arctg $[\tan 2\alpha/ \cos\theta)]$

For laser extensometer we have $\alpha = -24$°N and $\theta = 38.32°$ (Semibalamut et al., 2000). However an apparent azimuth can be deduced directly from the observed phase differences. In our case the phase lag of M_2 (65.4° in Table 5) fits perfectly $\Delta\varphi_2$ for a value $\alpha = -33$°N and the value for K_1 agrees reasonably well with the corresponding value $\Delta\varphi_1$=-71°. This apparent azimuth is thus shifted of –9°. It is probably related to the phase lag of 9° observed for M2 in our tiltmeter results due to cavity effect. In this direction the theoretical phase value of the amplitude factor is $F_2/\mathbf{l} = 8.203$ and, as we get in Table 5 $F2_{(M2)}=0.6901\pm0.0012$, we can derive the corresponding Shida number $\mathbf{l}_{(M2)} = 0.0841\pm0.0001$.

Annual analysis of strain data from 1990 to 2007 is presented on Figure 3. A nine years variation is apparent on the graph. Variations are associated with strong seismic activity in 1991, 1999 and 2008.

5. Tidal Analysis of Water Level Variation

Water level in the well (120 m depth, 2-3 m morena deposit over white marble) was sensitive to rainfall and reflects its seasonal variation (Figure 4). As tidal amplitude is very small, we use finite cavity model (Melchior, 1960**;** Figure 5):

$$dH = dV / [\pi\cdot r^2_w + (\rho\cdot g\cdot V / K_w)]. \qquad (1)$$

If the radius r_w is small we get: $dH = \Delta\cdot K_w / \rho\cdot g$, where $\Delta = dV / V$ is the cubic dilatation and K_w the elastic modulus of water. Using ETERNA program on the data of the second part of 2007 y. for volume variations, we got a phase disagreement. Phase agreement was obtained for horizontal strain with orientation 130°N (Table 6). It may be the result of crack system orientation along Talaya valley (40°N). Volume of crack can be estimated by adjusting the model. If we have for M_2 an experimental amplitude of 0.675 mm and a theoretical amplitude of 1.56 mm from the model ($dH = \Delta \cdot K_w / \rho \cdot g$), the amplitude reduction is connected with well size r_w. When relation (1), including crack volume and a well radius of 10cm, gives a correct estimation of the observed tidal amplitude, we can estimate parameters of crack system: crack depth – 100 m, crack width – 0.01 m, 30-50 cracks and crack length – 200 m. Formal use of Biot theory for confined aquifers for $dH/d\varepsilon = 0.10$ mm/nstr and barometric efficiency $\gamma = 2$ mm/KPa, allows to estimate elastic modulus $K_w = 0.2 \cdot 10^{10}$ Pa. for water. Orientation of crack system (40°N) is connected with Talaya valley orientation (Figure 7). Analysis results were used to estimate the effect of last earthquake (27/08/2008) on well level variation (Cooper et al., 1965, Figure 6). Stress jump was 0.045 MPa at 20 km distance from the epicenter.

6. Conclusions

We present results of tidal measurements with tiltmeters and extensometers in Talaya underground gallery (Baikal rift). The station is situated in a narrow mountain valley, on the boundary between Siberian platform and Baikal rift zone. Tidal analyses of tilt and strain data allow to separate cavity and geological effect. Quartz horizontal pendulums, well-sensor, tube and laser extensometers (25 m) were used with EDAS and other digital systems. Long-term tilt variation shows a loop with 18 year period followed by a westward drift. Three direction strain observation allow calculate main strain axes. Long-term variations were compared to regional seismological data. Laser extensometers data have been used for tidal analysis. Time variation of tidal amplitude and phase is presented. Then, after correction of local effect, the Love and Shida numbers calculated from combined strain tilt and gravity (Timofeev et al., 2000a, 2000b; Ducarme et al., 2008) data are $h = 0.6077 \pm 0.0008$, $k = 0.3014 \pm 0.0004$ and $l = 0.0841 \pm 0.0001$. Well-sensor was installed in a 120 m borehole at the bottom of the valley (200 m from underground gallery). Water tidal signal (M_2 – 0.67 mm) was analyzed by strain-program. Its phase is related with the valley orientation (40°N). Analysis results were used for estimations of last earthquake (27/08/2008) effect on well level variation. Stress jump was 0.045 MPa at 20 km distance from the epicenter.

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