Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Geodynamics 41 (2006) 205–212
JOURNAL OF GEODYNAMICS
http://www.elsevier.com/locate/jog

Strainmeters at Moxa observatory, Germany

Thomas Jahr*, Corinna Kroner, Andrea Lippmann

Institute of Geosciences, Friedrich-Schiller-University Jena, Burgweg 11, D-07749 Jena, Germany

Accepted 30 August 2005

Abstract

Since 1997, two quartz tube strainmeters at the Geodynamic Observatory Moxa, located 30 km south of Jena, are used to observe long-period horizontal deformation signals. Both strainmeters are 26 m long with orientations NS and EW and are installed in a gallery. To this system a third component was added in 1999, which connects the ends of the quartz tubes diagonally. This component is realised as a laser strainmeter, running through a 38 m long horizontal borehole. The first data analyses show high signal-to-noise ratios for the tidal frequencies and also the free oscillations caused by the Sumatra earthquake in December 2004 are clearly detectable.

It can be shown that the quartz strainmeter extending in EW direction generally contains significant more noise induced by barometric pressure than the NS-component. The laser strainmeter record shows strong influences of changing barometric pressure, due to the fact that the beam does not run in a vacuum. This influence is reduced in the higher frequencies by sealing the ends of the horizontal borehole with high quality glass. In addition, the observations are clearly temperature dependent and the influence of rainfall could be verified by two irrigation experiments.

Keywords: Strainmeter observations; Laser strainmeter; Environmental influences

1. Introduction

Regarding the observation of the deformation of the Earth crust and the global Earth strainmeters are the most important sensor systems besides gravimeters and tiltmeters. The deformation of the solid Earth due to tides and the normal modes after big earthquakes are detectable as well as local deformations, which can be caused by local tectonics or environmental variations.

The strainmeters are “classically” constructed as quartz or invar wire extensometers and are installed in galleries or caves, but also laser based systems are more and more deployed. Representatively for recent strainmeter developments and installations we refer to papers by Agnew and Wyatt (1989), Takemoto et al. (1993, 1998), Davydov and Dolgikh (1995), Gomberg and Agnew (1996), Amoruso et al. (1998), Onoue et al. (2001), Kopaev and Milyukov (2002) and Latynina and Vasil’ev (2003).

In the years from 1996 to 1999 the observatory Moxa was reconstructed, renewed and extended from the original seismological station to a geodynamic broadband observatory (Jahr et al., 2001). For the seismic frequencies the low

* Corresponding author. Tel.: +49 3641 948665; fax: +49 3641 948662.
E-mail address: thomas.jahr@uni-jena.de (T. Jahr).

0264-3707/$ – see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jog.2005.08.017

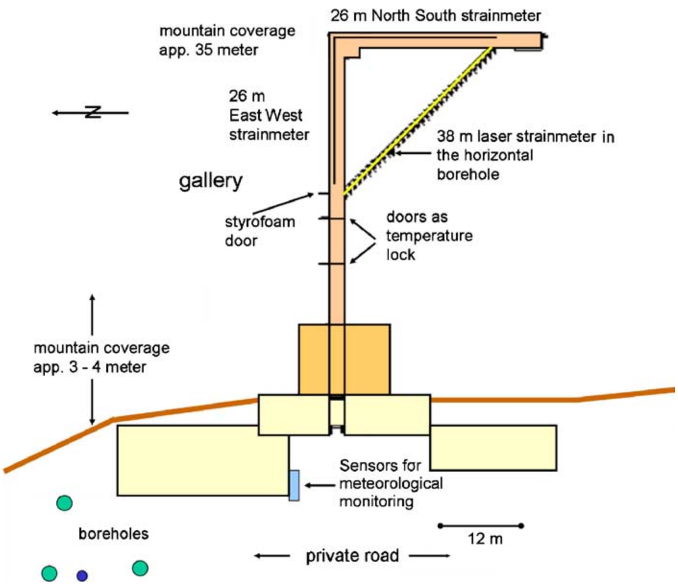

Fig. 1. Overview of the Geodynamic Observatory Moxa with location of the two quartz tube strainmeters and the laser strainmeter.

noise level at Moxa site was well known (Klinge and Teupser, 1988). This was confirmed also for the long (e.g. Earth tides) and the very long periods (polar motion) by Kroner (2002) and Kroner et al. (2004). The strainmeters are part and parcel of the Geodynamic Observatory Moxa. The optimisation of the installation inside the gallery and the identification of disturbing influences as well as their reduction are still the main objectives of the ongoing research,

Fig. 2. Installation of the laser strainmeter in the EW gallery, consisting of the control unit, the laser and the laser gun in front of the horizontal borehole.

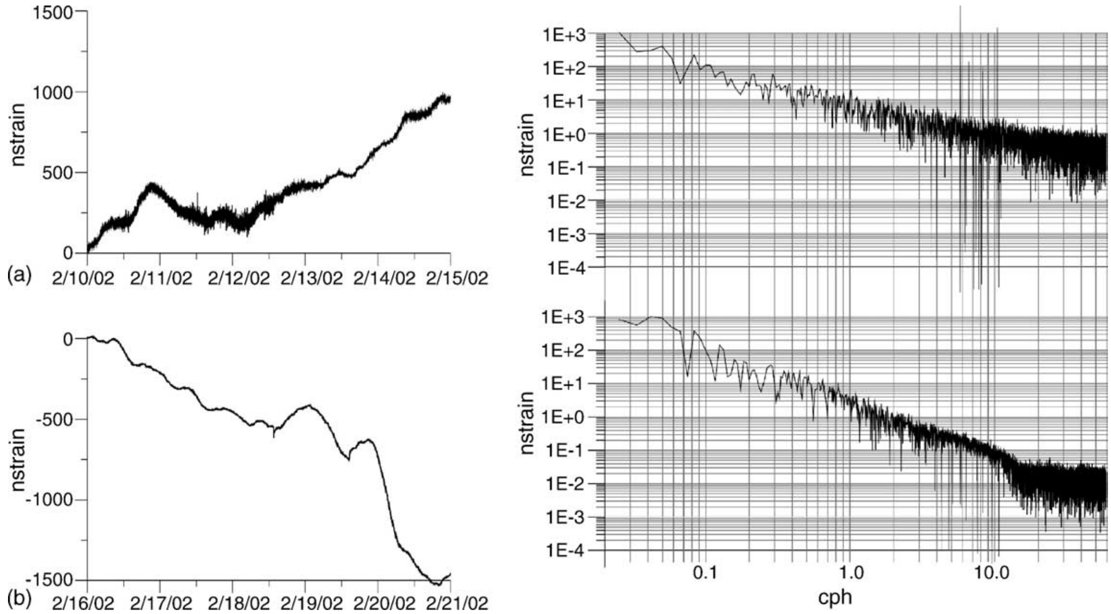

Fig. 3. Sealing of the horizontal borehole: (a) the data show an amplified level of high frequency noise, which is also visible in the spectrum, and (b) sealing the borehole improves the signal-to-noise ratio significantly as can be seen in the time series and the spectrum; 5-day long data examples.

because strainmeters are one of the most sensitive instruments regarding these two issues. This paper is dealing with these points.

2. Strainmeter installations at the Geodynamic Observatory Moxa

The Geodynamic Observatory Moxa was put into operation in 1964, purely under seismological aspects. Two quartz tube strainmeters, which are orientated parallel to NS and EW, were included but they were used only as strain seismographs until the 1990s. Both strainmeter components consist of 2 m long quartz tube segments, flanged together and suspended on Wolfram wires. Each end of the 26 m long strainmeters is deep seated with the underground; at the other ends at the elbow of the gallery (Fig. 1) inductive distance sensors (Hottinger) are attached. They observe the motion of the “free” end of the strainmeters in relation to a fixpoint. The measurement range is 0.2 mm with a dynamic range of 20 bit. The distance changes, e.g. due to the tidal caused deformation of the hill, can therefore be observed with a resolution in the subnano-range. The gallery is surrounded by schist of Lower Carboniferous, which means compact consolidated rocks, riddled with clefts.

Since 1997 the two quartz tube strainmeters are connected to the permanent monitoring equipment of Moxa observatory. The system was supplemented by a third horizontal component in March 1999 (Fig. 1). In cooperation with the company SIOS, Ilmenau, Germany, a laser strainmeter was installed, running through a 38 m long horizontal borehole (Figs. 1 and 2) but, due to the high complexity and high costs the laser beam is not running through vacuum. Its ends

Table 1
Noise in the tidal diurnal, semi-diurnal, terdiurnal and quarter-diurnal bands given by the Fourier-spectra of the residuals: due to the installation in the deepest part of the gallery the NS strainmeter shows the lowest noise level

Frequency intervals [cpd]	Noise		
	Laser strainmeter [nstrain]	Quartz NS strainmeter [nstrain]	Quartz EW strainmeter [nstrain]
0.800–1.193	0.3244	0.1212	0.2383
1.733–2.127	0.1809	0.0683	0.1113
2.800–3.193	0.0786	0.0604	0.0612
3.800–4.193	0.0570	0.0478	0.0430
0.01–6.0 (white noise)	0.0888	0.0357	0.0656

“connect” the fixed end points of the quartz tube strainmeters. The laser is based on the principle of the Michelson-inferometer and the laser strainmeter consist of a stabilised He–Ne laser with a wave length of 633 nm. The resolution of the installation in Moxa is 1.24 nm (SIOS, personal communication). The technical realisation of the laser equipment and the data acquisition under conditions of high humidity and low temperature were a challenge because the electronic and optical components usually are not designed for these conditions.

3. Data

The data of all three strainmeters are sampled with intervals of 10 s. Temperature changes are monitored at three sites inside the horizontal borehole and an additional barometric pressure sensor records changes at the end point of the laser beam. As a pure instrumental effect, due to fact that the laser beam is running through the air, the laser strain signal depends strongly on local barometric pressure fluctuations which result from changes in the refraction index of the air in the borehole. A significant improvement of the signal-to-noise ratio could be achieved by sealing the ends of the horizontal borehole with glass. The data example in Fig. 3 shows an amplified level of high frequency noise, which is significantly reduced after the sealing of the borehole (Fig. 3a and b). This effect is clearly discernible in the spectra of a 5-day long record before and after sealing: the noise of frequencies higher than 2 cph is reduced by about one order of magnitude. Unfortunately, the laser strainmeter recording was interrupted, due to a failure in the electronic control unit, just at the time of the big Sumatra earthquake on December 26, 2004 and the following days.

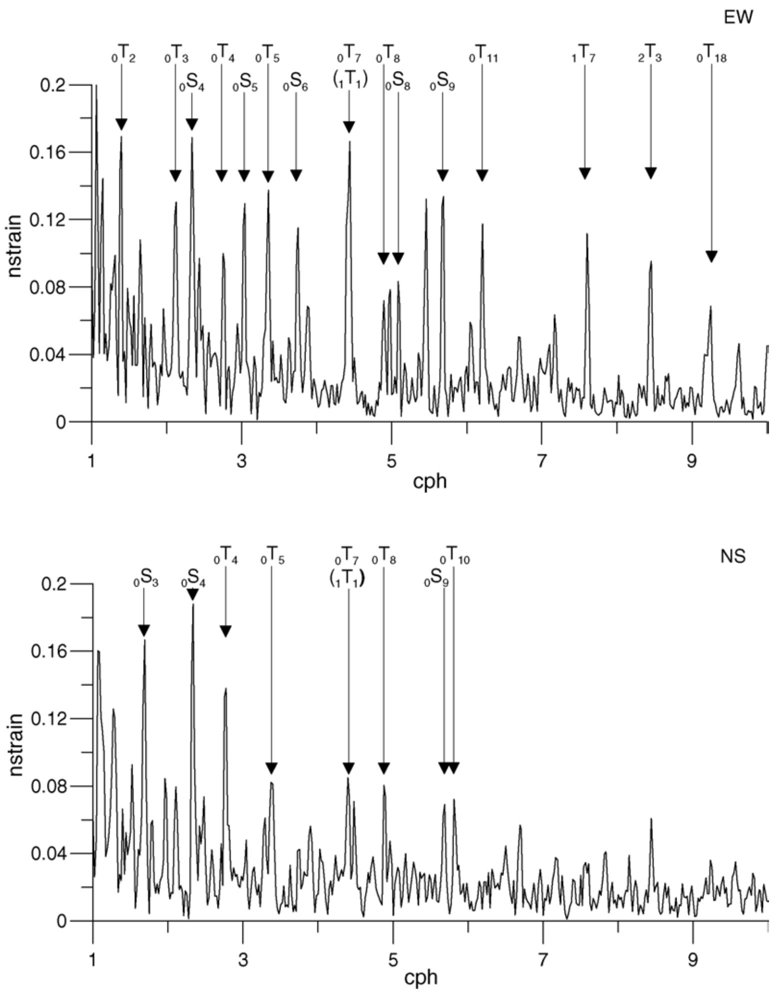

Fig. 4. Free modes of the Earth, due to the Sumatra earthquake on December 26, 2004. The spectra are calculated for 2 days after the earthquake, begin at 6 UT.

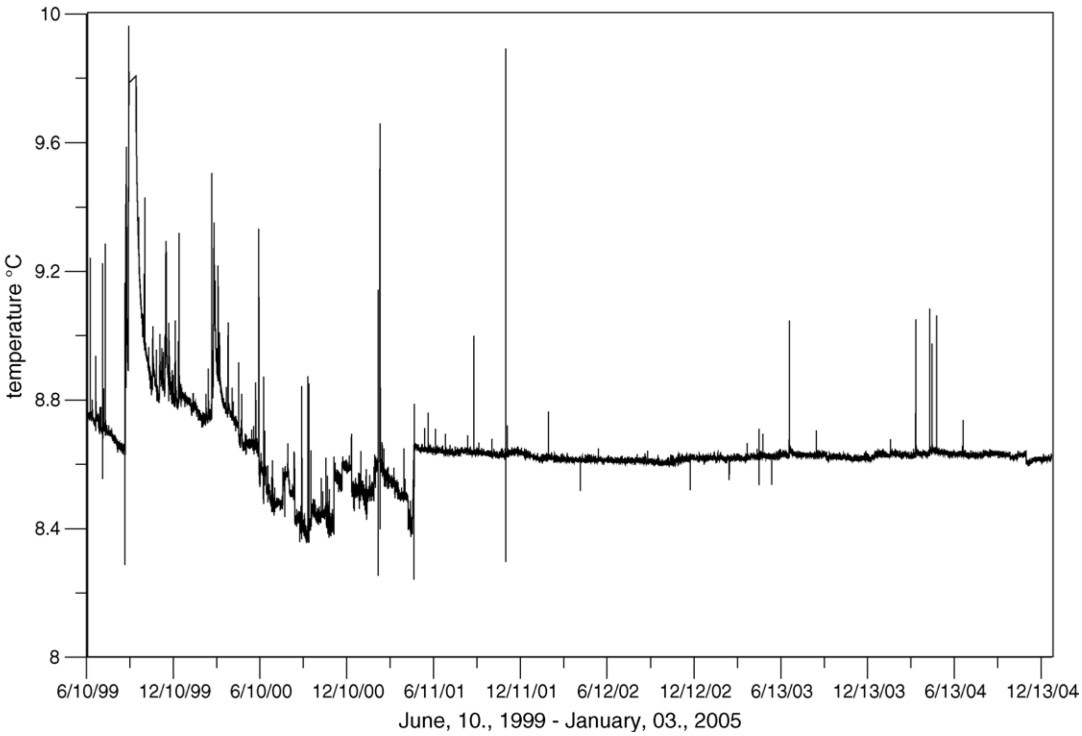

Fig. 5. Temperature inside the gallery. Since November 2001 after the reconstruction work was finished the temperature is constant (±0.1 °C) over the year, due to the cover of about 35 m. Spikes are due to unblocking the entrance of the gallery.

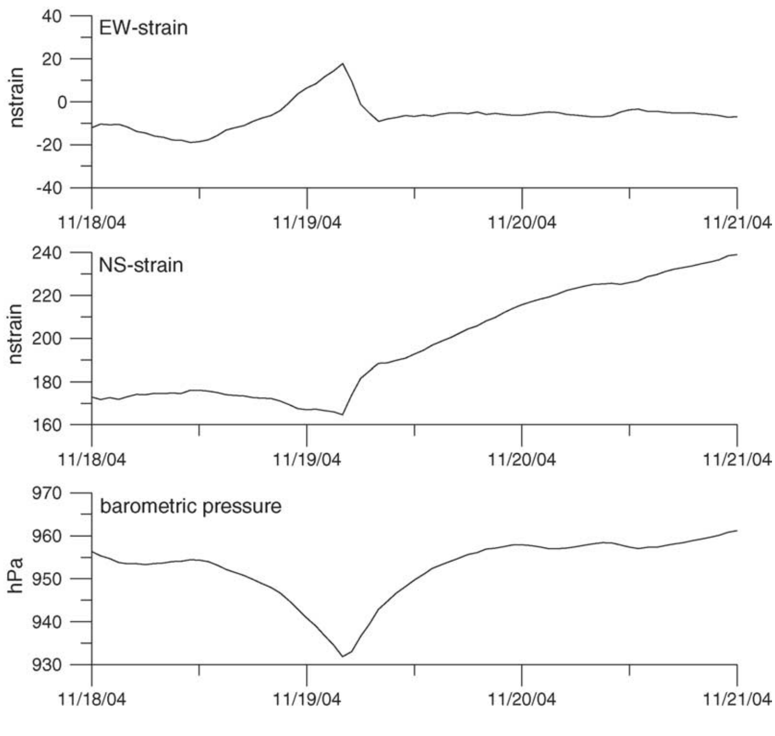

Fig. 6. Barometric pressure changes on November 19, 2004 (lower curve): both quartz tube strainmeters are significantly affected by the barometric pressure event. An increase of the strainmeter values means a compression of the surrounding rocks.

But this event and in particular the following free modes were observed by both quartz tube strainmeters with significant signal-to-noise ratios (Fig. 4). The spectra of the free modes clearly demonstrate the necessity of reducing noise in this frequency band. As only a few number of strainmeters exist in Mideurope, e.g. at the Black-Forest-Observatory, at Walferdange observatory or at the observatory in Sopron, these observations are of particular importance.

The tidal analyses were carried out for 13 main tidal constituents and the barometric pressure using the same 10 months of data (September 13, 2001–July 16, 2002) for all three strainmeter components. The noise was estimated by the Fourier-spectra of the residuals resulting from the tidal analysis. The comparison of the three strainmeter components shows the highest noise level for the laser strainmeter (Table 1), which is due to the fact that the sealing of the horizontal borehole was carried out only in February 2002. Therefore, the improved installation and the reduced noise level are applied only for the second part of the analysed data set of the laser strainmeter. Due to the installation in the deepest part of the gallery the NS strainmeter shows the lowest noise level. For the diurnal and semi-diurnal frequencies the EW strainmeter is about twice as much influenced by environmental noise sources as the NS strainmeter.

4. Environmental influences

The comparison of the strainmeter recordings with strain data of other observatories shows that we have to consider significant environmental influences on the strainmeters due to the instrument site.

Inside the gallery the environmental conditions are very stable regarding the temperature: due to the cover of about 35 m with rock the temperature of 8.6 °C is constant over the year with changes of ±0.1 °C. These stable conditions are achieved since November 2001 after the reconstruction works inside the gallery were finished (Fig. 5). However, barometric pressure changes influence all three strainmeters, which is clearly shown by the data example shown in Fig. 6. On November 19, 2004 a strong barometric pressure event was observed at Moxa (Fig. 6, lower curve). Both quartz tube strainmeters show an additional signal, as often also in this case the EW strainmeter (upper curve) is more

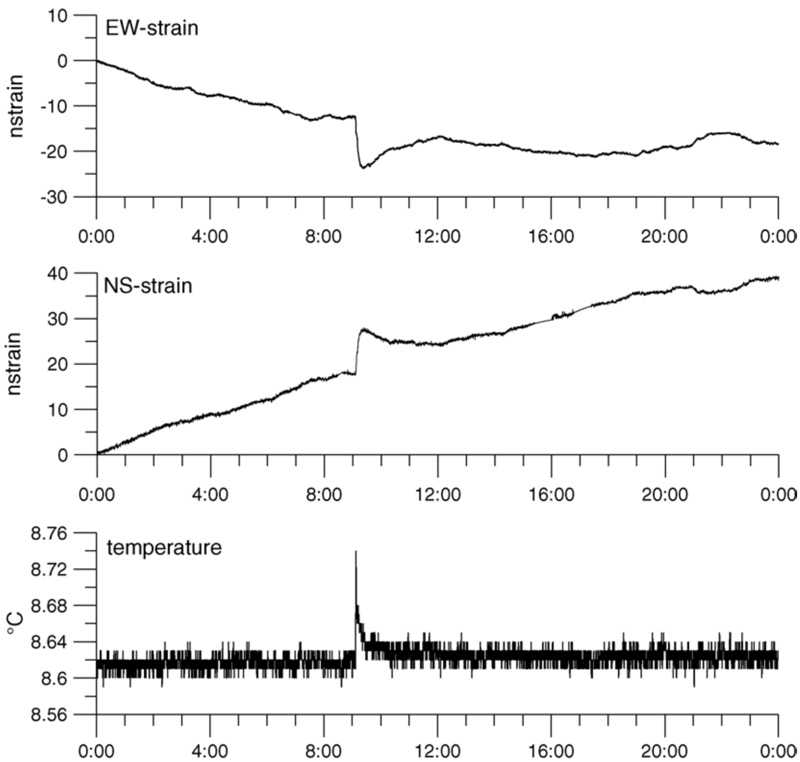

Fig. 7. Temperature changes on January 3, 2005 (lower curve): a temperature disturbance of about 1 h (opening of gallery door) causes an additional strain signal of about 4 h in both quartz tube strainmeters.

affected by the pressure front than the NS strainmeter (middle curve). In general, this influence is bigger by about 25%. A strong temperature influence on the quartz tube strainmeters is observed, too: a temperature disturbance of 0.12 °C during less than 1 h, due to entering of the gallery, yields strain influences of up to 6–8 nstrain over an interval of 4 h in both components (Fig. 7).

Besides the significant influences due to barometric pressure and temperature, it was suspected that also precipitation can affect the strain signals. For a verification of a relation between rain and strain due to pore pressure changes we carried out two irrigation experiments in April 2005. With the support of the voluntary fire brigade of Moxa about 30 m^3 water was irrigated on the upper part of the hill above the observatory and the change in strain and in the water level 20 m westwards of the EW strainmeter was observed. In the first experiment the water was mainly irrigated in a small NS running ditch and a small stripe of soil next to it (total width about 0.5 m). In the second experiment an area of about 800 m^2, 20 m above the ditch, was irrigated. A clear, additional induced strainmeter signal could be observed on both strainmeters (Fig. 8). Between 2 and 9 h after the begin of the experiments the water level increased by about 800 mm for experiment 1 and over 100 mm for experiment 2. Before this, both strainmeters show the induced signals with amplitudes between 10 and 70 nstrain. This means: also for precipitation like rain events but also snowmelt, we have to expect additional strain signals.

By numerical modelling relevant transfer mechanisms of pressure-induced signals could be identified and the observed effects qualitatively explained. These finite-element modelling gives explanations for the polarity of pressure-induced effects and the coupling of EW to NS phenomena (Kroner et al., 2005; Steffen et al., 2006). In addition, they could explain the observed dependency on the direction of the pressure wave but also on the topography in the vicinity of the observatory (Steffen et al., 2006; Kroner et al., 2005).

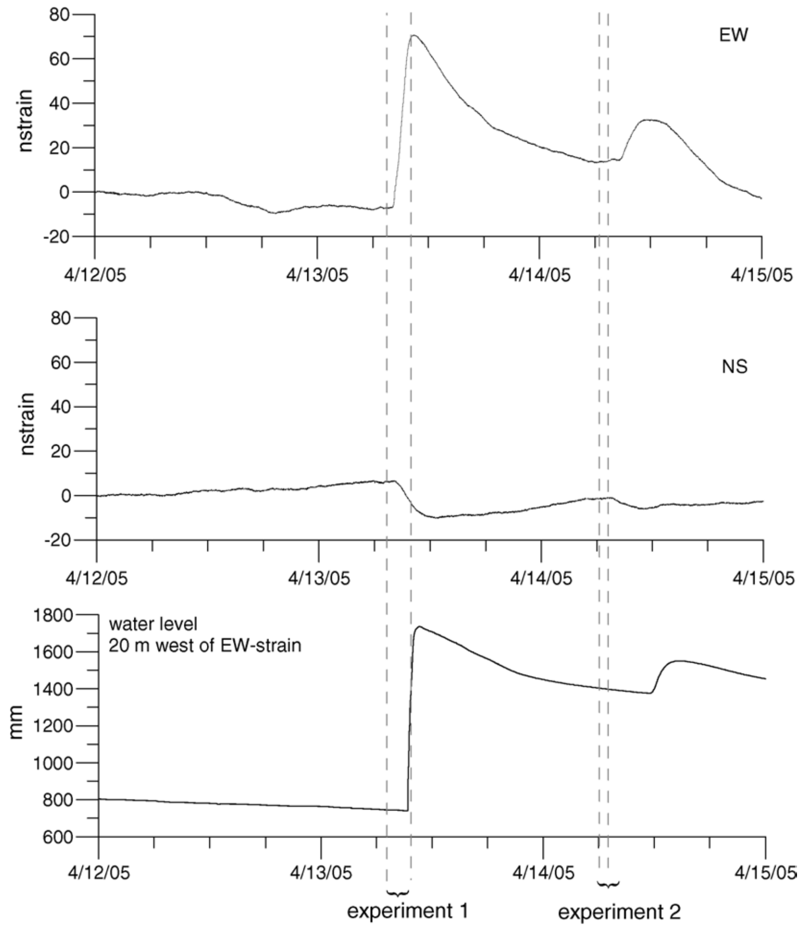

Fig. 8. Irrigation experiments and induced effects on the quartz tube strainmeters.

5. Conclusion

Three strainmeters are running since 1999 in the Geodynamic Observatory Moxa. It can be shown that the quartz strainmeter extending in EW direction contains significant more barometric pressure-induced noise than the NS-component. Both quartz tube strainmeters show also strong influences by precipitation, proved by two irrigation experiments. The laser strainmeter record is strongly influenced by changing barometric pressure, due to the fact that the beam does not run in a vacuum. This influence is minimised by sealing the ends of the horizontal borehole with high quality glass. Noise investigations in the tidal frequency band as well as the free mode analysis show the high quality of the strainmeter data.

Acknowledgements

The installation of the laser strainmeter was carried out in the frame of a cooperation with the company SIOS. We thank the colleagues from SIOS for the good cooperation. The financial support of this research project by the Government of Thuringia is gratefully acknowledged. For the experimental support regarding the sensor systems we thank Prof. Mentes, Sopron and the company Hottinger. A lot of experimental work was carried out by Jan Exß, which is gratefully acknowledged. We thank for the support of the fire brigade of Moxa, carrying out the irrigation experiments. Our thanks also go to the two reviewers, Dr. Dal Moro and Dr. Brimich for their helpful suggestions, which improved the manuscript considerably.

References

Agnew, D.C., Wyatt, F.K., 1989. The 1987 Superstition Hills earthquake sequence: strain and tilts at Piñon Flat Observatory. BSSA 79 (2), 480–492.

Amoruso, A., Crescentini, L., Scarpa, R., 1998. GIGS. Geophysical Interferometer at Gran Sasso. LNGS Annual Report 1997 and 1998, pp. 161–168.

Davydov, A.V., Dolgikh, G.I., 1995. Recording of ultralow-frequency oscillations by a 52.5 m laser strainmeter. Phys. Sol. Earth 31 (3), 248–251.

Gomberg, J., Agnew, D.C., 1996. The accuracy of seismic estimates of dynamic strains: an evaluation using strainmeter and seismometer data from Piñon Flat Observatory. BSSA 86 (1A), 212–220.

Jahr, T., Jentzsch, G., Kroner, C., 2001. The Geodynamic Observatory Moxa/Germany: instrumentation and purposes. J. Geod. Soc. Jpn. 47 (1), 34–39.

Klinge, K.D., Teupser, C., 1988. Fortschritte in der Observatoriumspraxis der Station Moxa. Gerlands Beitr. Geophys. 97, 229–242.

Kopaev, A., Milyukov, V., 2002. Environmental effects in tide strain observations near Mt. Elbrus Central Caucasus. Bull. d'inf. Marées Ter. 136, 10909–10916.

Kroner, C., 2002. Zeitliche Variationen des Erdschwerefeldes und ihre Beobachtung mit einem supraleitenden Gravimeter im Geodynamischen Observatorium Moxa. Jenaer Geowiss. Schriften 2.

Kroner, C., Jahr, T., Jentzsch, G., 2004. Results from 44 months of observations with a superconducting gravimeter at Moxa/Germany. J. Geodyn. 38 (3–5), 263–280.

Kroner, C., Jahr, T., Kuhlmann, S., Fischer, K.D., 2005. Pressure induced noise on horizontal seismometer and strainmeter records evaluated by FE modelling. Geophys. J. Int. 161, 167–178.

Latynina, L.A., Vasil'ev, I.M., 2003. The Earth surface deformations caused by air pressure variations. J. Geodyn. 35 (4–5), 541–551.

Onoue, K., Mukai, A., Takemoto, S., 2001. Tidal strain observed with extensometers in Donzurubo Observatory, Nara, Japan. J. Geod. Soc. Jpn. 47 (1), 141–147.

Steffen, H., Kuhlmann, S., Jahr, T., Kroner, C., 2006. Numerical modelling of the barometric pressure-induced noise in horizontal components for the observatories Moxa and Schiltach. J. Geodyn. 41 (1–3), 242–252.

Takemoto, S., Fujimori, K., Tanaka, Y., Yamamoto, T., Higashinaka, M., 1993. Continuous monitoring of crustal strain with a laser strainmeter in Kobe. Proceedings of the Eighth International Symposium on Recent Crustal Movements, Kobe. Geod. Soc. Jpn., 253–257 (special issue).

Takemoto, S., Otsuka, S., Fujimori, K., Mukai, A., 1998. Tidal strain observations at Rokko-Takao Station. In: Ducarme, B., Paquet, P. (Eds.), Proceedings of the 13th International Symposium on Earth Tides, Brüssel. Kobe, Japan, pp. 193–199.