

### Relations between microbarograph and strain data G. Mentes, I. Eper-Pápai

### G. Mentes, I. Eper I ap

### ▶ To cite this version:

G. Mentes, I. Eper-Pápai. Relations between microbarograph and strain data. Journal of Geodynamics, 2009, 48 (3-5), pp.110. 10.1016/j.jog.2009.09.005 . hal-00594431

### HAL Id: hal-00594431 https://hal.science/hal-00594431

Submitted on 20 May 2011

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

### Accepted Manuscript

Title: Relations between microbarograph and strain data

Authors: G. Mentes, I. Eper-Pápai

 PII:
 S0264-3707(09)00072-6

 DOI:
 doi:10.1016/j.jog.2009.09.005

 Reference:
 GEOD 899

To appear in: Journal of Geodynamics



Please cite this article as: Mentes, G., Eper-Pápai, I., Relations between microbarograph and strain data, *Journal of Geodynamics* (2008), doi:10.1016/j.jog.2009.09.005

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

#### 1 Relations between microbarograph and strain data

- 2 G. Mentes<sup>\*</sup>, I. Eper-Pápai
- 3 Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences;
- 4 Csatkai Endre u. 6-8., H-9400 Sopron, Hungary.
- 5 \*Fax: +36-99-508-355
- 6 E-mail: mentes@ggki.hu
- 7 Abstract

8 The relationship between barometric and strain data related to seasonal characteristics within 9 a year was studied on the basis of parallel records from a quartz tube extensometer and a 10 microbarograph at the Geodynamical Observatory in Sopronbánfalva, Hungary. Both strain and barometric data series were combined into groups according to the three 'Lloyd' seasons 11 12 and they were subjected to spectrum, tidal, regression and coherence analysis. All of the 13 analysis methods establish long periods, with seasonally varying relations between 14 atmospheric pressure and linear deformation measurements in the tidal frequency band. We 15 found that the separate seasonal barometric correction of the strain data did not bring a 16 notable improvement in the diurnal band, while in the semidiurnal band the improvement was about 10% better than correcting the whole year's data in a single step. 17 18 Keywords: Atmospheric pressure; Barometric correction; Coherence analysis; Strain; Tidal 19 analysis

#### 20 1. Introduction

Atmospheric loading is one of the major factors that effects extensometric measurements by loading and deforming the Earth's surface. Barometric pressure variations have a complex influence on this kind of measurement, which means that the changes of atmospheric pressure on the whole Earth contribute to local deformations at any point on the Earth's surface. The pressure changes cause a direct deformation of the Earth's solid crust; they also have an

indirect effect by changing the ocean loading. In addition atmospheric pressure variations take 26 27 place in a wide timescale from seconds to years. Most papers deal with the effect of atmospheric pressure variations on gravimetric measurements, and therefore most authors 28 29 investigate only the radial displacement of the Earth's crust (e.g. Sun, 1995; Kroner and 30 Jentzsch, 1999; Boy et al., 2006). The effect of barometric pressure variations on extensometric measurements was less intensively studied, than the effects on gravimetric 31 measurements. However the high sensitivity (better than  $10^{-10}$  strain) of the extension 32 33 makes it possible to use them for investigation of the Earth's interior. The barometric pressure 34 induced "noise" may limit the extraction of very small signals of interest, e.g. long periodic 35 tides, resonant elastic deformations of the Earth's crust, etc. Farrel (1972) computed deformation caused by surface load. Rabbel and Zschau (1985) investigated the deformations 36 37 and gravity changes on the Earth's surface due to regional and global atmospheric pressure 38 variations in the case of a spherical radially stratified Earth. It was found that the principal horizontal strains may have amplitudes up to  $10^{-8}$  and  $\pm 1.5 \cdot 10^{-9}$  for seasonal changes in the 39 40 atmospheric pressure distribution. Van Dam and Wahr (1987) calculated the time dependent 41 effects of global atmospheric pressures on surface point positioning measurements and on 42 gravity observations. They found that the displacements and gravity fluctuations were 43 somewhat smaller during summer than winter months. Probably this is why the existing 44 barometric pressure reduction methods can only be used with a limited accuracy for 45 correction of strain data. Another problem is that the removal or reduction of barometric 46 disturbing signals from strain data series is much more difficult than with gravimetric 47 measurements, since the barometrically induced strain also depends on the properties of the 48 bedrock and on the topography in the vicinity of the observatory. This was investigated by 49 comparing the atmospheric pressure effects on a surface and a deep station by Mentes and 50 Eper-Pápai (2006). In the last decade some papers studied the attributes of disturbed strain

51 signals due to atmospheric pressure variations (e.g. Onoue and Takemoto, 1998). Among 52 others, Kroner et al. (2005) and Steffen et al. (2005) investigated the physical transfer 53 mechanism between the barometric pressure and strain changes by finite element modelling. 54 At the Geodetic and Geophysical Research Institute (GGRI) of the Hungarian Academy of 55 Sciences, some methods for removal of the barometric pressure variations from strain signals 56 were also studied (Mentes, 2000; Eper-Pápai and Mentes, 2002). Since the regression method, - together with other methods (see also Kroner and Jentzsch, 1999) – was not effective 57 58 enough to eliminate the atmospheric pressure effect from strain measurements, the aim of the 59 present research is to study the seasonal properties of the effects of atmospheric pressure variations on strain measurements using extensometric and local atmospheric pressure 60 records. In this paper the seasonal features of the barometric pressure, and relationships 61 62 between air pressure and strain data were investigated by spectrum, tidal, regression and 63 coherence analysis.

#### 64 2. Observations and data pre-processing

The Sopronbánfalva (a suburb of Sopron) Geodynamical Observatory in Hungary is located 65 66 on the Hungarian Austrian border in the eastern foreland of the Alps. Its coordinates are: latitude 47° 40' 55'' N; longitude 16° 33' 32'' E; height is 220 m a.s.l. The observatory is an 67 artificial gallery driven into gneiss. The depth of the gallery is about 60 m (see Fig. 8). A 68 69 much more detailed description of the observatory is given by Mentes (2005, 2008). In 1991 a 70 22 m long quartz tube extensioneter with an azimuth of 116° was installed in the gallery about 71 30 m from the entrance. The displacement of the free end of the extension extension by 72 a differential capacitive transducer. The instrument is calibrated daily by a built-in 73 magnetostrictive actuator (Mentes, 1991). In 1997 a highly sensitive (0.0024 hPa/mV) 74 microbarograph was developed at the GGRI for studying atmospheric tides (Mentes, 2004). 75 This instrument is installed separately from the extensioneter in a room about 10 m from the

76 entrance and 20 m from the extensometer. In addition to strain and atmospheric pressure 77 measurements, the inside and outdoor temperatures were also recorded. In the observatory the yearly and daily temperature variations are less than 0.5 °C and 0.05 °C, respectively. We did 78 79 not find any correlation (correlation coefficient was 0.03) between the microbarograph, the 80 strainmeter and the inside temperature data, so the direct effect of temperature on the instruments can be disregarded. In the middle of 2001, a high resolution 24 bits digital 81 82 voltmeter was installed for digitizing extensometric, barometric and temperature data. For the 83 sake of the uniform data series, we used only the data recorded between 2002 and 2006 in our 84 investigations. They were collected with a sampling rate of one sample/minute and were 85 filtered by the equipment's built-in anti-aliasing filter. To get one value per hour the data series were resampled by the decimate routine of the ETERNA 3.30 tidal analysis program 86 87 (Wenzel, 1996). Data series were also filtered by a high pass filter, with a cut-off frequency 88 of 0.8 cycles/day, before processing. For the strain analysis in the diurnal and semidiurnal 89 tidal bands, K1 (P1K1 group) and S2 waves were chosen because the K1 lunisolar diurnal 90 wave has about the same magnitude (58.4 percent of the magnitude of M2) as the S2 principal 91 solar wave (46.6 percent of the magnitude of M2). According to K1 and S2 waves, the 92 atmospheric tidal waves S1 and S2 were chosen for the barometric pressure analysis. 93 3. Investigation of the seasonal relationship between barometric pressure and strain

94 **data** 

#### 95 **3.1. Barometric pressure variation**

We calculated the monthly averages and standard deviations of the hourly atmospheric pressure data in each year to study how the magnitude of the atmospheric pressure changes depends on the seasons. To present the variation of the barometric pressure in a simple way, the average of the standard deviations was calculated for each month of 2002-2006. These averages and their standard deviations are presented in Fig. 1. It can be clearly seen that the

barometric pressure variations (average line) and their standard deviations (SD line) are
higher from October to April than from May to September.

#### 103 **3.2. Spectrum analysis**

104 We determined Fourier amplitudes in the frequency range of K1 (P1K1) and S2 strain and S1 105 and S2 barometric waves in each month of the period we investigated to inspect the yearly behaviour of the tidal waves regarding both strain and air pressure measurements. Figure 2 106 107 represents one typical amplitude spectrum for both strain and pressure data. The spectral 108 amplitudes were determined with an accuracy of about 0.25 nstr for deformation, and about 109 0.013 hPa for pressure data. Since only records of single months were subjected to spectrum 110 analysis, those tidal waves which are close to each other in frequency (P1 and K1) cannot be 111 separated and an annual periodic amplitude variation results. The theoretical strain tides for 112 the same geographical location were calculated and monthly spectral amplitudes were 113 determined and applied for correction of the amplitudes from the strain data. A simple 114 subtraction was made between the measured and the theoretical amplitudes. This diminished 115 the temporal tidal amplitude variations. Figure 3 presents the results of spectrum analysis 116 obtained for the year 2006. Calculations in other years show similar a tendency. In Fig. 3 the 117 measured and theoretical data amplitude differences (meas.-theor.), the barometrically 118 corrected measured and theoretical data amplitude differences (correct.-theor.) and amplitudes 119 from the measured pressure data (barog.) are delineated for both the diurnal and semidiurnal 120 frequency bands. The barometric correction was completed by means of the regression 121 method separately in each year in the investigated period. On the basis of the results obtained 122 for 2002-2006, we found that in the semidiurnal band the amplitude difference changes are 123 smaller than in the diurnal band, as shown in our example in Fig. 3. We ascertain from these 124 results that in the diurnal band, the correction of the barometric effect did not cause a marked 125 decrease of differences between corrected and theoretical amplitudes. Barometric correction

of deformation data seems to work moderately in the semidiurnal band where we observed asomewhat evened amplitude course of the corrected data.

#### 128 **3.3. Tidal analysis**

129 Through the following calculations we examined tidal parameter relationships on the basis of 130 the seasonal characteristics of air pressure, due to the global pressure system variations. Both 131 extensometric and barometric data were classified into seasonal groups, according to the three 'Lloyd' seasons denoted by "D", "E" and "J" months for tidal and regression analysis 132 133 (Chapman and Lindzen, 1970). D months are: November, December, January and February 134 (centred on the winter solstice); J months are: May, June, July and August (centred on the 135 summer solstice) and E months are: March, April, September and October (centred on the 136 equinoxes). This grouping takes the similar weather conditions and barometric pressures into 137 consideration for the investigations. Tidal parameters were calculated by means of the 138 ETERNA 3.30 tidal analysis program (Wenzel, 1996) using the Wahr-Dehant Earth model 139 (Wahr, 1981; Dehant, 1987). Calibrated atmospheric pressure data was subjected to the 140 analysis as a gravitational component, giving adjusted amplitudes in the original physical unit. 141 In the tidal model, amplitude lines around only S1 and S2 waves were applied. Yearly data 142 series (2002-2006) were constructed for the tidal analysis according to the seasonal groups. Each yearly data series begins on 1st of November of the previous year and ends on 31st of 143 144 October of the actual year, e.g. the data series year 2002 is: 01.11.2001-31.10. 2002. In each 145 year (2002-2006), the amplitudes of the K1, S2 strain and S1, S2 barometric tidal waves were 146 separately calculated in the D, E and J months by the ETERNA 3.30 program. Averages of 147 the five amplitudes in each group was determined, and presented in Fig. 4. Figure shows 148 clearly that the larger the amplitude of the diurnal barometric wave S1 is the smaller the 149 amplitude of the corresponding strain wave K1. Changes in the semidiurnal band (def S2 and

bar\_S2) are much smaller than in the diurnal band, and changes in the opposite direction arenot so pronounced as in the diurnal waves (def K1 and bar S1).

#### 152 **3.4. Regression analysis**

153 Regression coefficients were calculated between the strain and atmospheric pressure data 154 series, taking the strain values as a function of the pressure data. Calculation of the regression coefficients was carried out on individual year data and on seasonal segments of the series. 155 156 Standard deviation of the coefficient's determination varies randomly between 0.1-0.3 157 nstr/hPa. Results are shown in Fig. 5. In our former publication (Mentes and Eper-Pápai 158 2006), the phase relationship between deformation and air pressure in tidal frequency bands 159 were investigated, and no phase shift was detected in the Sopronbánfalva Observatory. 160 Regression coefficients were separately calculated for March, April and September, October 161 in the E months' group, and their averages were calculated (E months' average). There is a 162 large difference between coefficients obtained for March, April and September, October. 163 Coefficients of D months and E months' averages differ slightly from the yearly coefficients, 164 especially in 2004-2006. J months' values are smaller than the others, and they reflect the fact 165 that variation of the atmospheric pressure is smallest in summer. 166 We compared the Fourier amplitude spectra of residual data series after tidal analysis of both 167 corrected and original strain data, to examine whether seasonal correction of strain data yields 168 better results than applying a yearly based linear regression correction. No significant 169 amplitude decrease was found in the diurnal tidal band compared to the one year data 170 processing, which makes the efficiency of seasonal correction questionable. However in the 171 semidiurnal band residual amplitudes decreased by 20-30 % when seasonal groups are 172 applied, and this is 10% improvement against the one year processing. Results from residual 173 inspections agree with Fourier amplitude investigations in Section 3.2 to some extent, as there 174 we found a slight amplitude improvement only in the semidiurnal band.

#### 175 **3.5. Coherence calculations**

176 Coherence analysis was also used to control the efficiency of the regression correction. First 177 we computed coherence between theoretical tide as the input signal, and the uncorrected 178 strain data as the output signal. The coherence function describes the mechanical and electric 179 transmission of our observatory instrument system. Next the computation was repeated using 180 the corrected strain data as the output signal. The results obtained for 2005 are shown in Fig. 181 6. We obtained similar curves for all of the years we investigated. The coherence value in the 182 semidiurnal band is very nearly 1, in contrast with the diurnal band where it is 0.8 without 183 correction. The suppressed transmission in the diurnal band is in accordance with our former 184 tidal results (Mentes and Eper-Pápai, 2006). In the diurnal band the efficiency of the correction is somewhat better than in the semidiurnal 185 186 band. In spite of this fact, the coherence value is smaller than 0.9. It means that either the 187 correction is not effective enough in this frequency band or there are other disturbing effects. 188 Mentes (2002) investigated the effect of temperature variations on deformation data as a 189 possible source of noise, though in that work the long term changes were taken into account 190 without considering tidal frequencies. In the present study we made some comparisons using 191 coherence analysis, taking such data series as output signals, corrected for both pressure and 192 temperature. The resulting coherence values coincide with the barometrically corrected data, 193 and no improvement was found. Our other investigations show that the close phase 194 relationship between temperature and pressure components harden the separation of the 195 different effects.

#### **4. Discussion**

Barometric pressure variation and average barometric pressures are smaller in the summer
months than in the others (Fig. 1). The situation is the same in the regression coefficients
which are also somewhat smaller in J months than in D and E months (Fig. 5). This feature of

the regression coefficients can be more clearly seen in Fig. 7. In this Figure the average
regression coefficients, the average amplitudes (determined by tidal analysis) of the
barometric waves S1 and S2 obtained for D, E and J months (in 2002-2006) are given for
each month. Regression analysis shows that the changes of the regression coefficients along
with the variations of the barometric pressure beside a seasonal periodic change also have a
random variation.

Spectrum analysis shows the semidiurnal band is less disturbed by barometric pressure 206 207 variations than the diurnal band. Regression correction also gives better results in the 208 semidiurnal band which is supported by both the spectral amplitude values in Fig. 3 and the 209 residual analysis after tidal calculations. The magnitude of the variations of barometric 210 pressure in the diurnal band is about three times higher than in the semidiurnal band. Monthly 211 amplitude changes of the strain waves are opposite to the amplitude changes of barometric 212 waves in both tidal bands, although it is not obvious at first sight in the semidiurnal band 213 (Figs. 3 and 4). Coherence calculation gives the same results. These findings can be explained 214 by the topography of the observatory. Figure 8 shows the cross section of the surroundings of 215 the observatory constructed from the digital terrain model in the axis of the extension terrain. 216 instrument is perpendicular to the high steep rock face and is about 30 m from it, so the 217 changes of the barometric pressure cause large strain variations in the direction of the 218 extensometer (horizontal arrow in Fig. 8), while the horizontal deformation caused by the 219 vertical pressing force (vertical arrows) can be neglected. The situation is also confirmed by 220 the fact that the tempestuous blasts of wind appear in the extensionetric data records, since the 221 steep rock face is perpendicular to the prevailing wind. 222 The resulting opposite change of the barometric pressure amplitudes relative to the values of

the regression coefficients requires explanation which we suppose is in the characteristics of

- the topography and properties of the rock (inhomogenities, clefts, faults, etc.) near the
- 225 observatory. Further investigations are needed to reveal the reasons for this phenomenon.

#### 226 **5. Conclusions**

227 Our investigations brought some new results which aim to improve barometric pressure

- 228 correction for linear deformation measurements. Seasonally completed regressional correction
- 229 yields better results than taking a whole year data series. There is about a 10% improvement
- 230 in the semidiurnal band and no improvement in the diurnal band. However, tidal parameters
- 231 can be determined with higher accuracy from long continuous data series. Further difficulty
- arises with seasonal air pressure correction for strain data, since there will be jumps at the turn
- 233 of the seasons and they should be handled in data processing.
- 234 Analysis results show different behaviour of seasonal barometric corrections in the main tidal
- 235 bands. This raises the need for finite element modelling of our observatory's surroundings to
- thermal and pressure disturbance investigations.

#### 237 Acknowledgements

- 238 This research was supported by the Hungarian National Scientific Research Fund (OTKA) in
- the research project K71952. The authors are very grateful to Tibor Molnár for his careful
- 240 maintenance of the instruments. We thank Walter Zürn and Thomas Jahr for the thorough
- 241 review of the manuscript which helped to improve this paper.

#### 242 **References**

- 243 Boy, J-P., Ray, R., Hinderer J., 2006. Diurnal atmospheric tide and induced gravity variations.
- 244 J. Geodyn. 41, 253-258.
- 245 Chapman, S., Lindzen, R.S., 1970. Atmospheric Tides. D. Reidel Publishing Co., Dordrecht,
- 246 Holland, p. 200.
- 247 Dehant, V., 1987. Tidal Parameters for an Unelastic Earth. Physics of the Earth and Planetary
- 248 Interiors, 49, 97-116.

- 249 Eper-Pápai, I., Mentes, G., 2002. The Effect of Atmospheric Pressure on Strain
- Measurements at the Sopron Observatory, Hungary. Bull. d' Inf. Marees Terr. 137, 1090110906.
- Farrell, W.E., 1972. Deformation of the Earth Surface Loads. Rev. Geophys. Space Phys. 10
  (3), 761-797.
- 254 Kroner, C., Jentzsch, G., 1999. Comparison of Different Barometric Pressure Reductions for
- 255 Gravity Data and Resulting Consequences. Phys. Earth Planet. Int. 115, 205-218.
- 256 Kroner, C., Jahr, T., Kuhlmann, S., Fischer, K. D., 2005. Pressure Induced Noise on
- 257 Horizontal Seismometer and Strainmeter Records Evaluated by Finite Element Modelling.
- 258 Geophys. J. Int. 161, 167-178, doi:10.1111/j.1365-246X.2005.02576.x.
- 259 Mentes, G., 1991. Installation of a Quartz Tube Extensometer at the Sopron Observatory.
- 260 Bull. d'Inf. Marees Terr. 110, 7936-7939.
- 261 Mentes, G., 2000. Influence of Temperature and Barometric Pressure Variations on
- 262 Extensometric Deformation Measurements at the Sopron Station. Acta Geod. Geoph. Hung.

263 35 (3), 277-282.

- 264 Mentes, G., 2004. Atmospheric Tide Obtained by the Microbarograph Developed at the
- 265 Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences. Acta
- 266 Geod. Geoph. Hung. 39 (1), 39-48.
- 267 Mentes, G., 2005. Results of Tidal Research. Acta Geod. Geoph. Hung. 40 (3-4), 293-305.
- 268 Mentes, G., 2008. Observation of Recent Tectonic Movements in the Pannonian Basin. J.
- 269 Geodyn. 45, 169-177.
- 270 Mentes, G., Eper-Pápai, I., 2006. Investigation of Meteorological Effects on Strain
- 271 Measurements at Two Stations in Hungary. J. Geodyn. 41 (1-3), 259-267.

- 272 Onoue, K., Takemoto, S., 1998. Atmospheric Pressure Effects on Ground Strain Observation
- 273 at Donzurubo Observatory, Nara, Japan. In: Proceedings of the 13th International Symposium
- 274 on Earth Tides, Brussels, 22-25 July 1997, 157-164.
- 275 Rabbel, W., Zschau, J., 1985. Static Deformations and Gravity Changes at the Earth's Surface
- due to Atmospheric Loading. J. Geophys. 56, 81-99.
- 277 Steffen, H., Kuhlmann, S., Jahr, T., Kroner, C., 2005. Numerical Modelling of the Barometric
- 278 Pressure Induced Noise in Horizontal Components for the Observatories at Moxa and
- 279 Schiltach. J. Geodyn. 41, 242-252.
- 280 Sun, H.-P., 1995. Static Deformation and Gravity Changes at the Earth' Surface due to the
- 281 Atmospheric Pressure. PhD Thesis, Cath. Univ. Louvain, Belgium
- 282 Van Dam, T.M., Wahr J.M., 1987. Displacements of the Earth's Surface due to Atmospheric
- 283 Loading: Effects on Gravity and Baseline Measurements. J. Geophys. Res. 92, B2, 1281-
- 284 1286.
- 285 Wahr, J.M., 1981. Body Tides on an Elliptical, Rotating, Elastic and Earth without Oceans.
- 286 Geophys. J. R. astr. Soc. 64, 677-703.
- 287 Wenzel, H.G., 1996. The Nanogal Software: Earth Tide Data Processing Package ETERNA
- 288 3.30. Bull. d'Inf. Marees Terr. 124, 9425-9439.

### 289 Figure captions

- **Fig. 1.** Average variability of the barometric pressure in different months of 2002-2006 (1
- 291 January to 12 December)
- **Fig. 2.** Typical amplitude spectra for measurement data (April 2006)
- 293 Fig. 3. Monthly spectrum amplitude differences of strain and theoretical strain (meas.-theor.),
- 294 corrected strain and theoretical strain (correct.-theor.) as well as amplitudes of barometric
- waves (barog.) in the diurnal and semidiurnal bands in 2006

CC CC

- **Fig. 4.** Average of the amplitudes obtained for D, E and J months from 2002 to 2006
- 297 **Fig. 5.** Regression coefficients between barometric and strain data
- **Fig. 6.** Coherence between the theoretical tide and the uncorrected and barometric corrected
- 299 strain data
- 300 Fig. 7. Average regressional coefficients and tidal amplitudes of air pressure data from 2002-
- 301 2006 for each month
- 302 Fig. 8. The cross section of the surroundings of the observatory made from the digital terrain
- 303 model in the axis of the extension ter. The azimuth of the cross section is  $116^{\circ}$ .



# Figures





### **Fig. 1.**



- **Fig. 2**.



- **Fig. 3.**







