Environmental effects in tide strain observations near the Mt. Elbrus, Central Caucasus

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Abstract

Results of tide strain observations with laser interferometric strain meter located near the sleeping volcano Mt. Elbrus during the 1998-2000 are presented. Sophisticated procedure of data processing using TSOFT, Preterna and Eterna programs helped to get reliable signal/noise ratio for M2 wave (up to 100) in spite of extremely high environmental perturbations. Simplified correction for topographic effect gave rather low value of amplitude coefficient of about 0.7 that could be caused by the influence of shallow hot magma chamber.

1. Introduction

Northern part of the Main Caucasian Ridge (*Fig. 1*) represents one of the most tectonically active regions of Russia and is characterized with intensive crustal movements reaching 1.5 cm/year. So-called Elbrus block is of particular interest as it houses the highest top of Europe – famous sleeping volcano Mt. Elbrus, see *Fig. 2*.

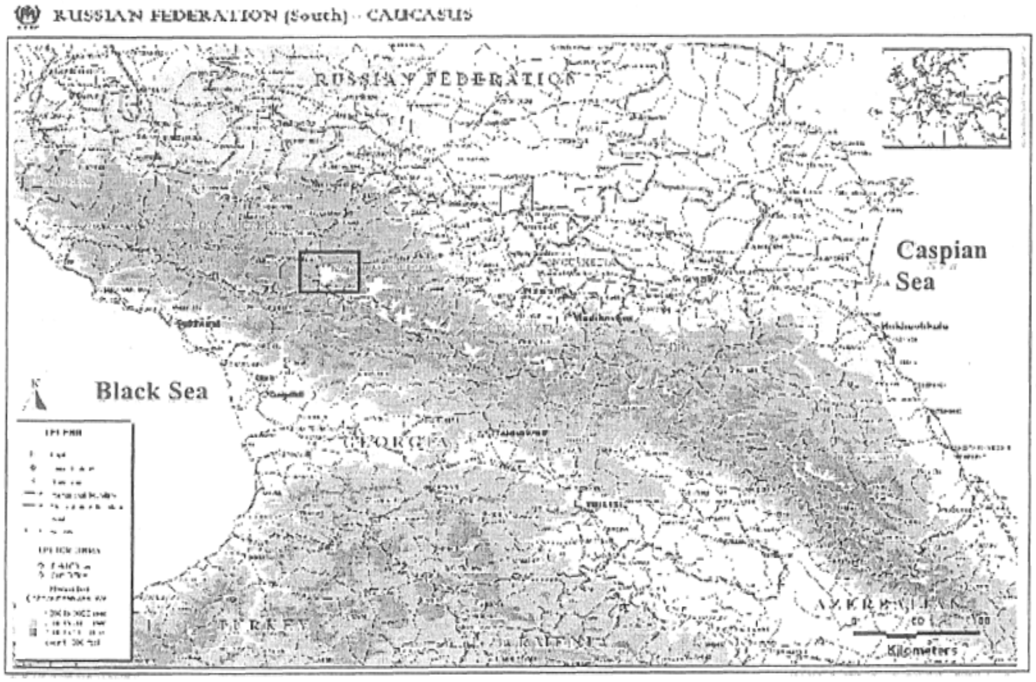


Fig 1. Southern Russia and Caucasus. Black box represents the Mt. Elbrus area, see *Fig. 2*.

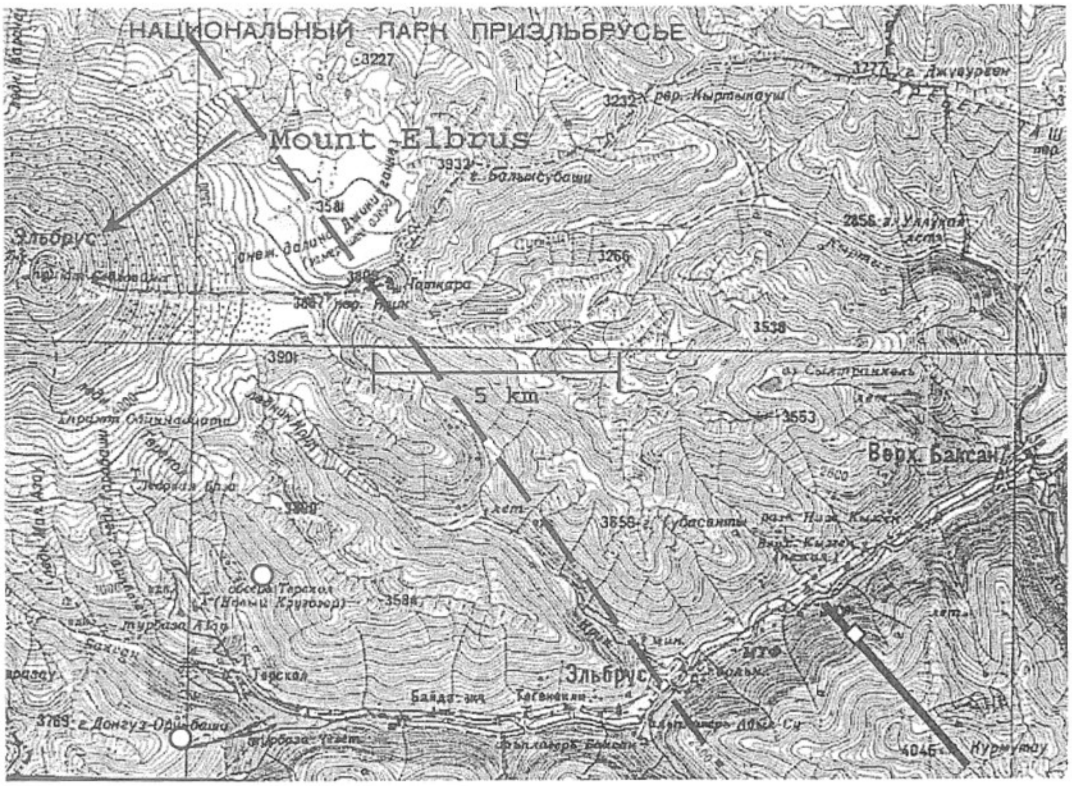


Fig. 2. Location of Baksan geodynamical observatory. Thick black line denotes the tonnel, small open box - location of laser strain meter. Small open circles represent locations of GPS points, observed in 1993 and 1994 by IfAG. The nearest fault is denoted by thick dashed line.

Elbrus is classified as an active volcano according to UNESCO, as its last eruption took place some 1700 years ago and there exist a lot of geophysical implications about the possibility of its awakening *(Bogatikov et al., 1998, Kopaev et al., 1995).*

The only habitated area near the Mt. Elbrus is Baksan Valley, where a lot of small towns with hotels for climbers and tourists exist. Up to 100 000 people visit this area each year, 10 % of which come from Western Europe, USA and Japan.

The Baksan geodynamical observatory of Sternberg Astronomical Institute of Moscow State University is located in this valley, 15 km apart from Elbrus in rock massive on the depth of 600 m in 4.2 km long technological tonnel of Baksan Neutrino Observatory of of Institute of Nuclear Research of Russian Academy of Sciences (*Fig. 2, 3*). This tonnel houses two unique scientific installations – Underground Scintillation Neutrino Telescope and Gallium-Germanium Neutrino Telescope located at the depths respectively of 500 and 3500 m from the entrance.

The observatory is equipped with a laser interferometric strain meter of Michelson type with non-equal arms ($L_{observational}$ = 75 m, $L_{reference}$ = 0.5 m) located in the main non-thermostatized tonnel and oriented along its axis (latitude = 43°12’, longitude = 42°43’, azimuth = 150°37’). Thermostatized room of observatory is isolated from tonnel and houses two pillars, larger one has been used for absolute gravity observations by FG’5-101 of IfAG in 1994 *(Wilmes et,* *1994).* Smaller pillar has been used for tide gravity observations with modernized Sodin-gravimeter in 1998-1999 *(Kopaev and Yushkin, 2000).* A gravity calibration baseline with range of 127 mGal is installed along a 4.2 km long tonnel. Observations have been carried out in 1992-2002 using 6 Sodin gravimeters (S208, S209, S210, S212, S311and S312) that have been calibrated using Moscow calibration baseline and tilt calibration platforms, the accuracy of gravity values ranges from 12 to 21 mGal. Two additional common outdoor calibration baselines exist in this area, one with range of 650 mGal, and second with range of 85 mGal. They are equipped with excellent pillars, but as the uplift in this area is of the order of 1.5-2 cm/year, its stability is at the moment under our checking. Two GPS-stations exist in this area, they are located very close to the Elbrus itself (see *Fig. 2,* third one is located 30 km to the East) and have been observed twice with IfAG team in 1993 and 1994 *(Wilson et al, 1994).*

The laser strain meter has been in use starting from 1993 with irregular observations for evaluation of its performance and numerous improvements, so the early data are of limited quality and are used only for seismic studies, mainly for investigation of eigenvibrations of the Earth.

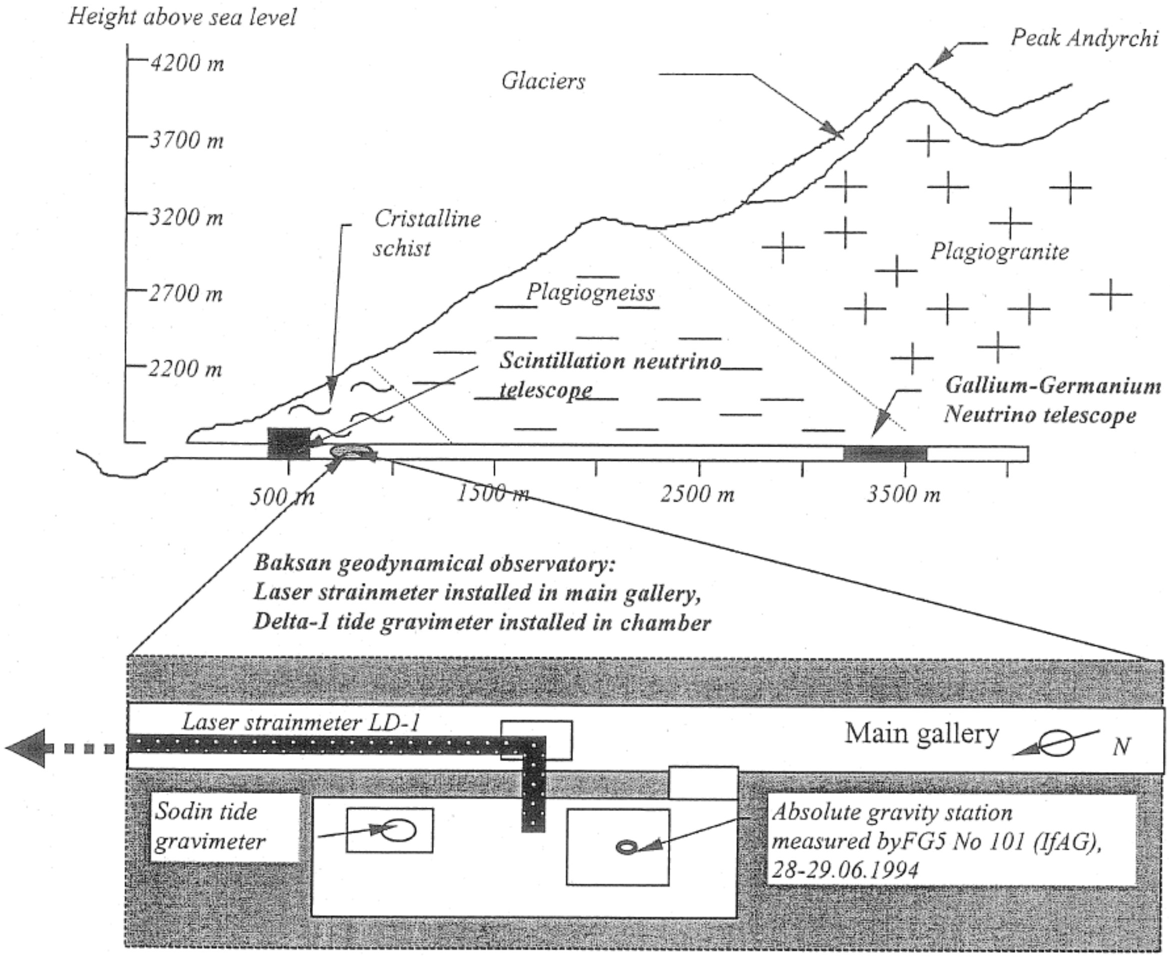


Fig. 3. Geological cross-section and situation of Baksan Geodynamical Observatory.

2. Description of Baksan laser strain meter

Laser interferometers represent perfect (but rather expensive) devices for strain measurements as they have infinite dynamic range, high precision and “build-in” usually perfectly stable permanent calibration possibility.

Optical system and path of the Baksan laser interferometer are located in specially constructed tanks and pipes under the vacuum of 10^{-5} mm Hg, which is supported by 2-stage system of vacuum pumps. Parameters of frequency stabilized He-Ne laser are the following: wavelength $l = 0.63$ mm; power = 2 mWt; relative instability of $l < 10^{-9}$/day.

Laser radiation is modulated on the frequency of 60 Hz by means of electro-mechanical modulation of laser resonant cell.

A very sophisticated feedback system for strain recording is used that includes electro-mechanical galvanometer, rotating mirror and photodetector. If the displacement exceeds the value of one interferometric fringe (l/2, of 0.3 mm), feedback systems turns the mirror and returns to the center of interferometric pattern by introducing the step of l/2 into the signal. This steps offer an ideal permanent calibration and are removed automatically during the preprocessing procedure.

All the parts of strain meter (laser, beam-splitters, reflecting mirrors, vacuum chambers) are located on special pillars deepened into the bedrock that are isolated from tonnel floor. Vacuum pumps are installed on special sand “pillows” to reduce microseismic noise caused by its permanent operation.

Temperature and atmospheric pressure variations are recorded simultaneously with deformation signal using respectively SKIBA microbarograph with resolution of 1 mBar and self-made thermistors with resolution of 0.001 K.

3. Tide strain observations and data processing

Long term observations suitable for tide strain investigations started in spring of 1998 (with many gaps caused by numerous problems due to the vacuum pump malfunction, power supply interruptions and different logistic problems), so the data coverage is of about of 50 % only. As the device itself is located in the open ventilation tonnel for neutrino installations, no thermal insulation exists at all and all the outdoor temperature changes cause thermal deformations of the rock and different parts of instrument. It is obvious from the excellent correlation of long-term strain signal with temperature variations (*Fig. 4*).

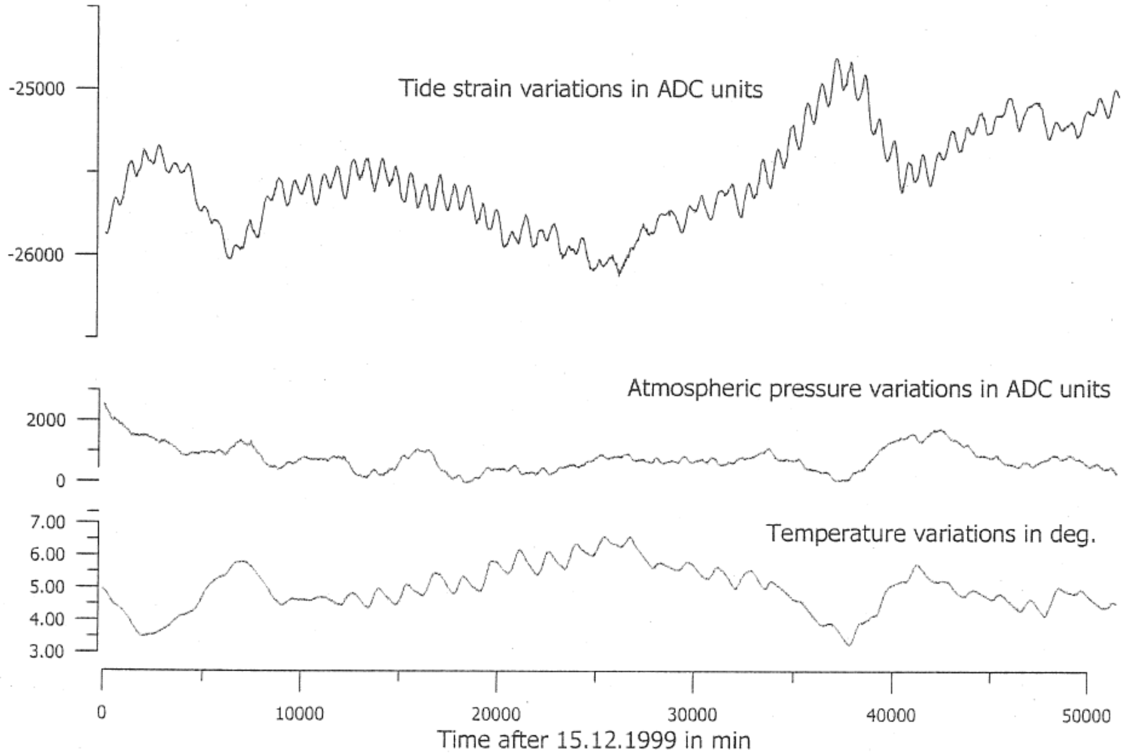


Fig. 4. Example of tide strain record obtained with Baksan laser strainmeter

That is why we started our tidal data processing with a lot of doubts. But after some experiencing the appropriate techniques has been developed that includes: 1) common PRETERNA data processing; 2) using TSOFT for consecutive band-pass filtering of hourly strain, temperature and pressure data in semi-diurnal (between 11 and 13 hours) and diurnal (from 22 to 26 hours), following search for best correlation between the different channels by means of its mutual shifting; 3) application of ETERNA to strain data together with shifted pressure and temperature data and 4) return to PRETERNA with known strain/pressure and strain/temperature admittances, and so on. Two or three iterations are usually enough to get best possible (in our case) signal to noise ratios of 10-20 for O1 wave and 50-100 for M2 wave and standard deviation of hourly values of 2-3 nstrain. In the beginning of the process this ratios are usually 2-5 times worse. The data occasionally represent a set of blocks, separated by gaps of different duration varying form several days to several months, so these blocks were processed first separately and all the results are represented in *Table 1* and *Fig. 5*. Than a common processing has been carried out for the whole data set of almost 400 days. The results are represented in *Table 2* as a standard ETERNA listing.

Table 1. Summary of Baksan laser strainmeter data tidal analysis during 03.1998 – 07.2000

Wave	O_1			M_2			σ, nstr	Pressure admittance, nstr/mBar	Temperature admittance, nstr/°C
Time interval (N_{days})	S/N	Amplitude factor	Phase, deg.	S/N	Amplitude factor	Phase, deg.			
1998									
04.03–25.04 (52)	14	1.02 ± 0.07	-5 ± 4	85	1.01 ± 0.01	+1 ± 1	2	+0.7 ± 0.2	2.1 ± 0.1
24.07–18.08 (26)	*4*	*0.7 ± 0.2*	*-13 ± 17*	*61*	*1.09 ± 0.02*	*+1 ± 1*	*6*	*+3 ± 1*	*0.4 ± 0.6*
1999									
20.02–27.03 (35)	*4*	*0.5 ± 0.1*	*+23 ± 14*	*33*	*0.93 ± 0.03*	*-21 ± 2*	*4*	*+3.7 ± 0.4*	*0.4 ± 0.2*
28.03–24.04 (27)	18	0.97 ± 0.05	-5 ± 3	51	1.01 ± 0.02	-3 ± 1	2	-0.1 ± 0.3	*23 ± 1*
14.05–09.06 (27)	18	1.28 ± 0.06	+7 ± 3	50	1.04 ± 0.02	-3 ± 1	2	-0.6 ± 0.3	0.8 ± 0.2
11.06–29.07 (43)	14	1.3 ± 0.1	-8 ± 4	66	1.05 ± 0.02	+2 ± 1	2	+0.2 ± 0.1	0.2 ± 0.1
24.09-19.10 (26)	12	0.77 ± 0.07	-4 ± 4	43	0.74 ± 0.02	+2 ± 1	2	-0.7 ± 0.4	1.0 ± 0.1
25.11-31.12 (37)	10	1.1 ± 0.1	-8 ± 6	95	0.79 ± 0.01	+1 ± 1	2	+0.5 ± 0.2	0.03 ± 0.07
2000									
03.01–08.02 (36)	8	1.2 ± 0.1	-8 ± 7	47	1.03 ± 0.02	+1 ± 1	3	-1.7 ± 0.3	6 ± 1
23.02–15.04 (51)	7	1.0 ± 0.2	+4 ± 9	45	1.02 ± 0.02	-3 ± 1	3	-0.3 ± 0.2	3.5 ± 0.3
15.04–17.05 (31)	13	1.0 ± 0.1	-14 ± 4	65	1.03 ± 0.02	+8 ± 1	3	-0.1 ± 0.3	1.3 ± 0.1
18.05–18.07 (61)	9	0.9 ± 0.1	+1 ± 6	45	1.03 ± 0.02	0 ± 1	4	-0.1 ± 0.3	1.2 ± 0.1
Mean	11	0.98 ± 0.17	-1 ± 3	57	0.98 ± 0.03	-1 ± 2	3	0.4 ± 0.5	1.5 ± 0.5
Common adjustment	15	0.98 ± 0.07	-3 ± 3	65	0.98 ± 0.01	-1 ± 1	4	0.4 ± 0.1	0.56 ± 0.03
Common adjustment with series 2,3 excluded	20	1.07 ± 0.05	-4 ± 3	76	0.98 ± 0.01	1 ± 1	3	0.2 ± 0.1	0.86 ± 0.03

4. Discussion

We are not very satisfied with results, however this tonnel represents the only possible place to put interferometer and it cannot be isolated due to the clear technical reasons, so our aim was to do all the best. Nevertheless, the application of optimized combination of ETERNA, TSOFT and PRETERNA helps to reduce the huge influence of environmental disturbances up to appropriate level, at least for M2 wave. Signal/noise ratios for M2 ranging between 50 and 100 are rather common for usual non-laser strain meters. The same values for O1 range between 10 and 20 only, obviously due to the residual thermal influence and could hardly be reduced. They are not represented on *Fig. 4.* Nevertheless the common processing of all the data reveals clearly the K1 wave, however K1/O1 amplitude ratio (0.85) is considerably larger than its theoretical value 0.6). Temperature and pressure admittances as well as corresponding time lags (not shown in Table 2, ranging from 2 to 6 hours for atmospheric pressure and from 4 to 8 hours for temperature) show chaotic variations in amplitude and even in sign (for pressure admittance). The latter one is however mostly statistically insignificant that is confirmed with common adjustment of best data (last row in *Table 1*). Temperature admittance is on the contrary mostly statistically significant and its value is close to 1 nstr/°C. All the error bars on the *Fig. 5* correspond to 2s, whereas simple 1s standard deviations are listed in Table 1.

As for time variations of the amplitude of M2, it is obvious that only two blocks reveal statistically significant decrease to value of 0.7-0.8 from the mean value close to 1.0, covering the time period approximately from September to December of 1998. This anomaly is not associated in time with any large disturbances in pressure and temperature admittances, like first blocks, so it could be of natural origin. We show on *Fig. 5* also the time evolution of monthly averaged seismic energy in area with radius of 50 km around the observatory. A series of small

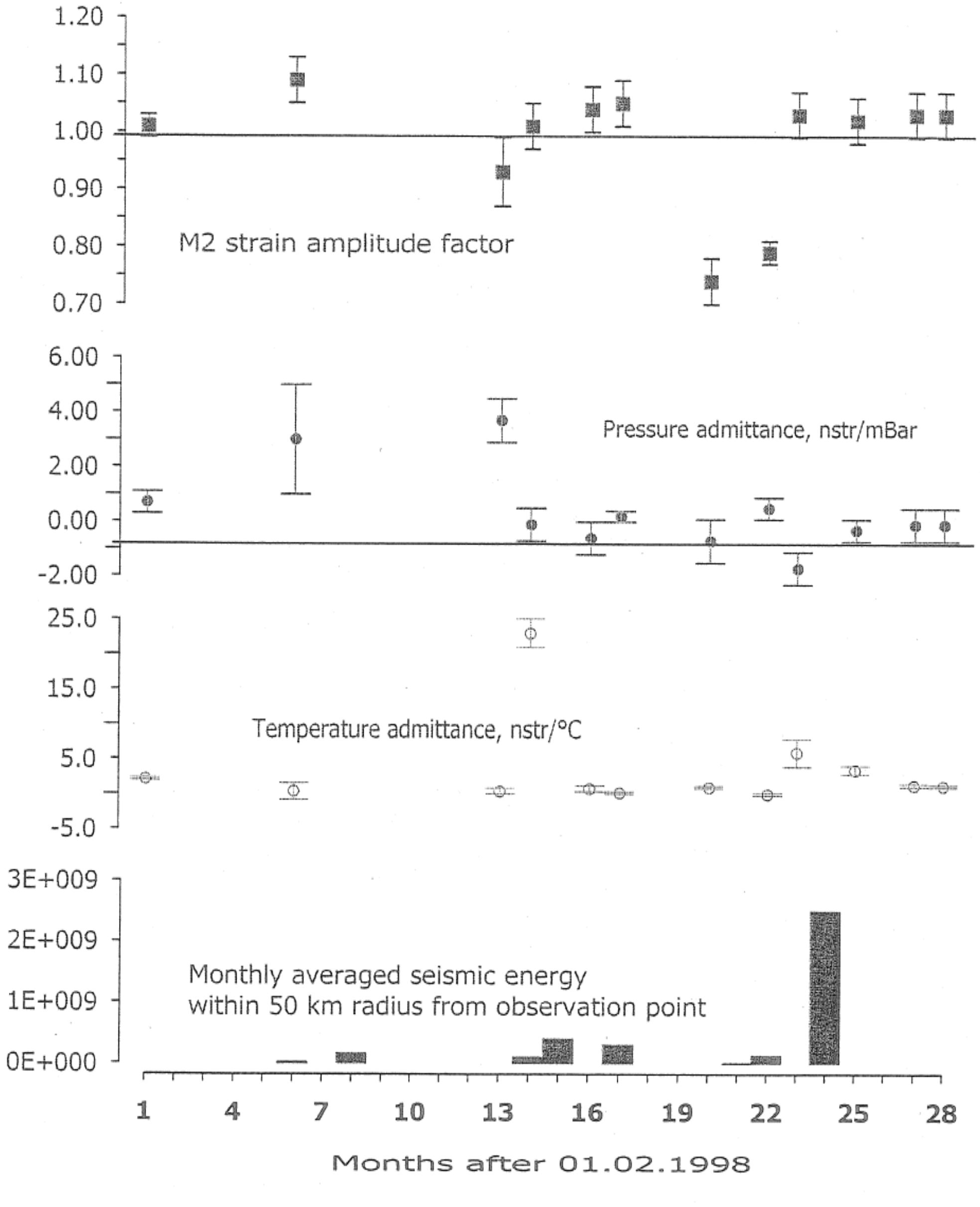
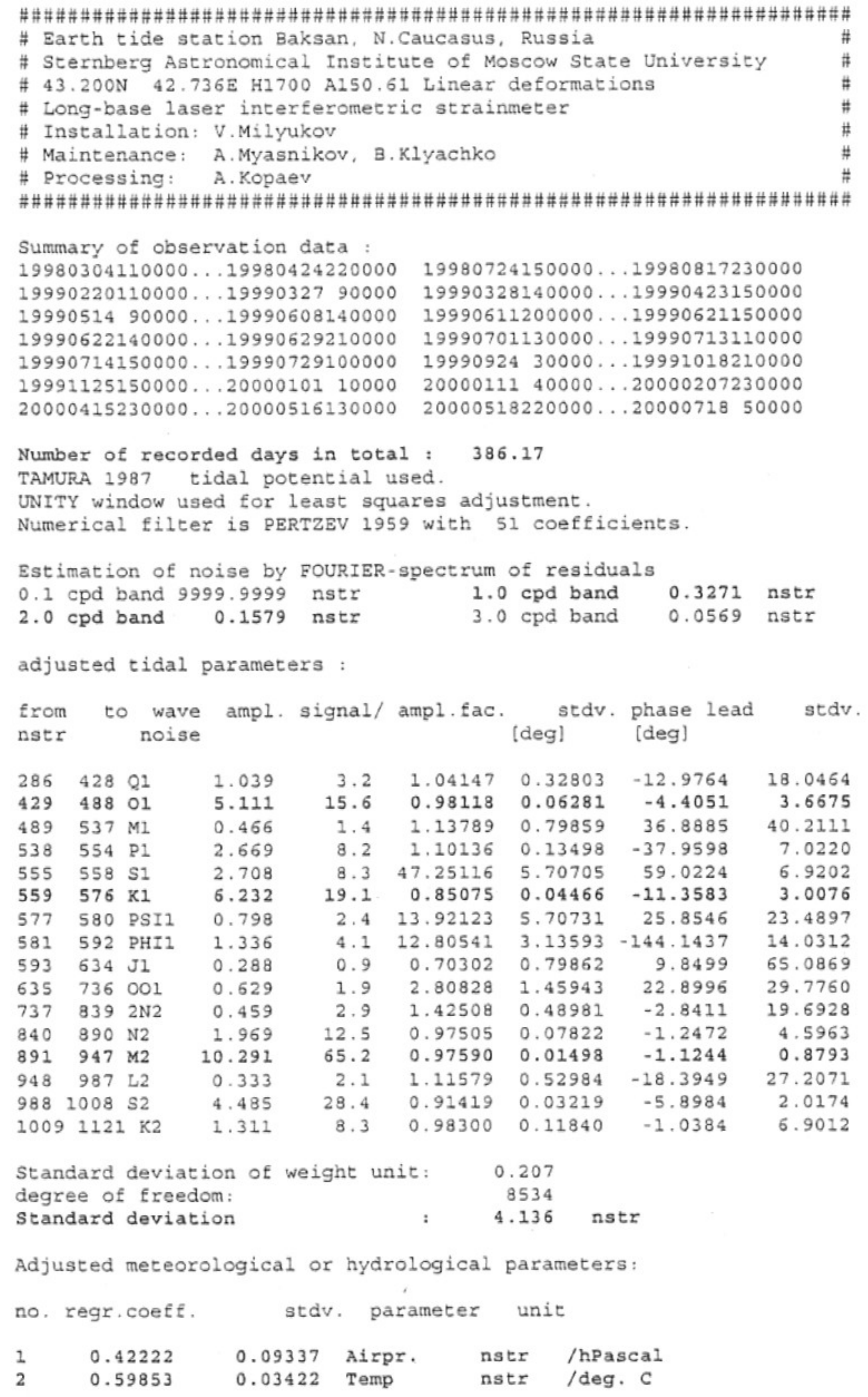


Fig. 5. Summary of Baksan laser strain meter data tidal analysis during 03.1998 - 07.2000.

Table 2. Results of common data processing for tide strains for the whole observat



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######################################################################
# Earth tide station Baksan, N.Caucasus, Russia                       #
# Sternberg Astronomical Institute of Moscow State University         #
# 43.200N  42.736E H1700 A150.61 Linear deformations                  #
# Long-base laser interferometric strainmeter                         #
# Installation: V.Milyukov                                            #
# Maintenance:  A.Myasnikov, B.Klyachko                               #
# Processing:   A.Kopaev                                              #
######################################################################

Summary of observation data :
19980304110000...19980424220000  19980724150000...19980817230000
19990220110000...19990327 90000  19990328140000...19990423150000
19990514 90000...19990608140000  19990611200000...19990621150000
19990622140000...19990629210000  19990701130000...19990713110000
19990714150000...19990729100000  19990924 30000...19991018210000
19991125150000...20000101 10000  20000111 40000...20000207230000
20000415230000...20000516130000  20000518220000...20000718 50000

Number of recorded days in total :   386.17
TAMURA 1987   tidal potential used.
UNITY window used for least squares adjustment.
Numerical filter is PERTZEV 1959 with  51 coefficients.

Estimation of noise by FOURIER-spectrum of residuals
0.1 cpd band 9999.9999  nstr         1.0 cpd band    0.3271  nstr
2.0 cpd band    0.1579  nstr         3.0 cpd band    0.0569  nstr

adjusted tidal parameters :

from   to  wave  ampl. signal/ ampl.fac.    stdv. phase lead    stdv.
nstr       noise                          [deg]      [deg]

286   428 Q1      1.039      3.2   1.04147  0.32803  -12.9764   18.0464
429   488 O1      5.111     15.6   0.98118  0.06281   -4.4051    3.6675
489   537 M1      0.466      1.4   1.13789  0.79859   36.8885   40.2111
538   554 P1      2.669      8.2   1.10136  0.13498  -37.9598    7.0220
555   558 S1      2.708      8.3  47.25116  5.70705   59.0224    6.9202
559   576 K1      6.232     19.1   0.85075  0.04466  -11.3583    3.0076
577   580 PSI1    0.798      2.4  13.92123  5.70731   25.8546   23.4897
581   592 PHI1    1.336      4.1  12.80541  3.13593 -144.1437   14.0312
593   634 J1      0.288      0.9   0.70302  0.79862    9.8499   65.0869
635   736 OO1     0.629      1.9   2.80828  1.45943   22.8996   29.7760
737   839 2N2     0.459      2.9   1.42508  0.48981   -2.8411   19.6928
840   890 N2      1.969     12.5   0.97505  0.07822   -1.2472    4.5963
891   947 M2     10.291     65.2   0.97590  0.01498   -1.1244    0.8793
948   987 L2      0.333      2.1   1.11579  0.52984  -18.3949   27.2071
988 1008 S2       4.485     28.4   0.91419  0.03219   -5.8984    2.0174
1009 1121 K2      1.311      8.3   0.98300  0.11840   -1.0384    6.9012

Standard deviation of weight unit:      0.207
degree of freedom:                       8534
Standard deviation               :      4.136   nstr

Adjusted meteorological or hydrological parameters:

no. regr.coeff.       stdv.  parameter   unit

1      0.42222     0.09337  Airpr.      nstr   /hPascal
2      0.59853     0.03422  Temp        nstr   /deg. C
```

seismic events (M < 2.5) occurred some 20 km to the North-East from observatory. The fact that our anomalous decrease in M2 amplitude preceded this events looks too encouraging and speculative (even in terms of *(Beamont and Berger, 1974)*) at the moment especially because of bad data coverage.

As for the mean undisturbed value of amplitude for M2 wave, the configuration of 2D topography *(Fig. 3)* with slope of more than 30 degrees should increase the actual value by about 20-30 % according to the maps of Harrison and Blair (*Harrison, 1976; Blair, 1976*) and simplified estimations based on S.Molodenski analytical techniques for 2D relief approximated by linear spline *(Molodenski, 1985, 1986).* So the actual value is of the order of 0.7-0.8 and this anomaly could be attributed (rather speculatively at the moment, before the finite element modeling) to the presence of hot and shallow magma chamber revealed from analysis of Bouguer gravity and seismic data *(Bogatikov et al, 1998),* that could result in decrease of elasticity and therefore of tidal strain amplitudes. As the nearest fault is parallel to the strain meter axes *(Fig. 2)* and the latter one is located sufficiently far from the extremities of the tonnel *(Fig. 3),* we don't expect any serious influence of the fault or cavity on the obtained result.

The value of phase lag for M2 equals however to $-1.1^{\circ} \pm 0.9^{\circ}$ and is therefore statistically insignificant.

5. Conclusion

Application of sophisticated data processing techniques resulted in successful determination of amplitude of main tidal semidiurnal M2 wave from the highly thermally disturbed data from Baksan laser strain meter installed in Baksan valley, 15 km apart from sleeping volcano Mt. Elbrus, including statistically significant decrease of M2 amplitude before the sequence of small seismic events in the vicinity of strain meter.

Amplitudes of tidal strains observed in Mt. Elbrus area are low (70 % of model values for M_2) and could be explained by rough topography influence as well as by the presence of magma chamber.

Observations with laser strain meter in such an area are unique, so a way to improve the data coverage should be pursued.

6. Acknowledgements

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