T1.2-P36

The preliminary tidal analysis based on the CG-5 AUTOGRAV gravity measurements at Lenkaran station (Azerbaijan)

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CTBT: Science and Technology Conference 2017

CTBT: SCIENCE AND TECHNOLOGY 2017 CONFERENCE

Vienna | Austria| 26–30 June 2017

Introduction and Background

The study of the tidal variations in gravity is one of the perspective methods of geodynamic studies. Tidal variations in gravity are caused by the influence on the earth of variable in space and time the lunar-solar exposure. Experimental data is important in the development of models of tidal deformation, for the calculation of tidal corrections in high-precision measurements of gravity, in high-precision geophysical measurements that reflect the variations of strain and stress in the Earth's crust, to determine the displacements of the earth's surface in the geocentric coordinate system.

Currently, the Earth's tidal observations are widely implemented in many countries, but the number of stations of earth tidal observations is far from enough. In addition, the existing network of these stations is not evenly distributed. This creates difficulties of interpretation of the geodetic results. Therefore, increase in the reliability and the quality of the experimental data, as well as the geographical expansion of the observations is highly relevant.

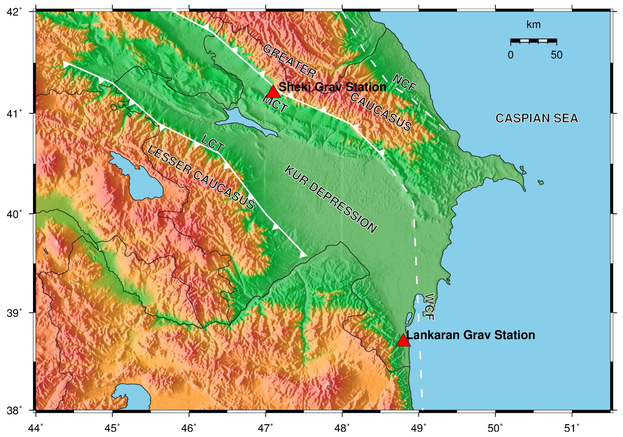


Figure 1.The location of tidal stations Lenkaran and Sheki placed on general tectonic map of the Azerbaijan. Red triangles are locations of Sheki and Lenkaran Gravity stations. Abbreviations: NCT = North Caucasus Thrust fault, MCT = Main Caucasus Thrust fault, LCT = Lesser Caucasus Thrust fault, WCF = West Caspian Fault, NCF =North Caspian fault.

Lenkaran gravity station

The territory of the Azerbaijan lie within the zone of plate interaction where the African and Arabian plates are actively converging with the Eurasian Plate.

Tidal measurements at the station Lankaran began in 2014 (Fig. 2). Excluding breaks in recording, the observations cover 524 days in a time span of little more than two years (from July 2013 to December 2016). We installed the high-precision gravitymeters Scintrex (Scintrex CG5 AutoGraf) (Fig. 2) with metal springs as the most stable by the metrological parameters of the mobile gravitymeters. It is one of the most common instruments for studying the Earth's tides.



Figure 2. Scintrex CG-5 AutoGrav gravitymeter in Lenkaran station (left), ZLS B-14 BURRIS gravitymeter in Sheki station (right).

Data analysis

The observation results were processed using a combination of programs PreAnalyse (Gebauer et al., 2007) and ETERNA (Wenzel, 1996). Dynamic of recording: For long-term Earth tide (ET) observations and secular studies we are using the function “Continuous observations”. This function permits the continuous measurement of gravity as required for Earth tide observations and secular gravity studies. Sample rate: The date sample rate was set to 3 minutes.

Time base: Date and time were adjusted to UTC. Interpolation of gaps: During the primary treatment we introduced gaps where data were missing.The 1 min samples were cleaned with PreAnalyse and filtered to 5 min- and 1-hour-samples (Fig.3). The graphs show the stable recording of the amplitude that point to the good work of gravimeter. Breaks in the time series are not significant. Time series were analyzed using program of tidal analysis ETERNA 3.4 (Wenzel, 1996). We have computed the amplitude and phase spectrum of the hourly time series (Fig. 4: amplitude in nm/s²; phase in degrees, Fig. 5).

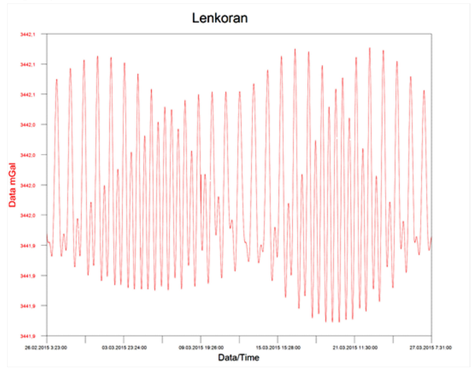


Figure 3. Fragment of recording on Lenkaran station over a period of 2 month.

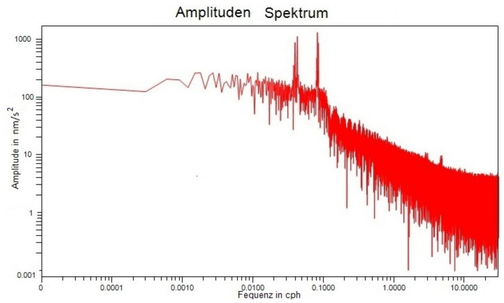


Figure 4. Amplitude spectrum in nm/s2

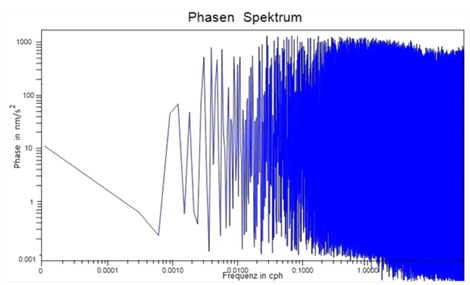


Figure 6.Phase spectrum in nm/s2

The values of the Earth's tidal parameters (amplitude (δ-) factor and phase delay) of the gravitational field for 9 major diurnal waves and 6 main semi-diurnal waves in the southern part of Azerbaijan has been obtained. Since the period of K1 tidal wave is approximately 23.93 hours, obviously, the direction of this peak period in the star frame of reference is not dependent either on the phase of the Moon or Sun, and consequently is not also on their gravitation. The main lunar semidiurnal wave M2 (the period is around 13.66 h) is the second-size amplitude-phase indicator of the elastic response of the Earth's crust on the tidal effect. Tidal O1 (the main lunar declined wave with period of 28.984104 h) is the third-size amplitude of the tidal wave.

Table 1. Adjusted tidal parameters

№	From [cpd]	To [cpd]	wave	amp. [nm/s²]	amp.fac.	stdv.	ph. Lead [deg]	stdv. [deg]
1	0.501370	0.911391	Q1	66.9994	1.14809	0.00059	-0.2264	0.0302
2	0.911391	0.947992	O1	350.0632	1.14852	0.00014	0.0748	0.0071
3	0.947992	0.981855	M1	27.4787	1.14692	0.00354	0.2027	0.1763
4	0.981855	0.998632	P1	160.2348	1.2227	0.01339	-0.2431	0.6791
5	0.998632	1.001370	S1	15.1679	6.2679	0.91712	3.0376	1.1271
6	1.001370	1.004108	K1	486.8788	1.13628	0.00010	0.1623	0.0048
7	1.004108	1.006846	PSI1	9.6845	2.96343	0.34758	-0.8137	0.9567
8	1.006846	1.023623	PHI1	8.7681	1.44248	0.14630	-0.2523	3.7468
9	1.023623	1.057448	J1	27.8045	1.16011	0.00149	0.0694	0.0735
10	1.057448	1.470244	OOI	15.1804	1.15806	0.00299	0.0966	0.1478
11	1.470244	1.880265	2N2	10.7144	1.158906	0.00113	2.0296	0.0557
12	1.880265	1.914129	N2	68.0310	1.17523	0.00027	1.8664	0.0134
13	1.914129	1.950420	M2	358.4098	1.18546	0.00006	1.4714	0.0031
14	1.950420	1.984283	L2	10.4062	1.21760	0.00250	1.7793	0.1178
15	1.984283	2.002737	S2	166.3527	1.182741	0.00014	0.2692	0.0069
16	2.002737	2.451944	K2	12.5347	2.5267	0.12176	2.4689	0.3479
17	2.451944	3.381379	M3	4.0508	1.07427	0.00372	0.1151	0.1984
18	3.381379	3.347615	M4	0.0145	0.33191	0.17547	-43.7812	30.2918

Sheki gravity station

The selection of the site Sheki in Azerbaijan was just based on its remoteness from the oceanic activity and effects of Caspian Sea and Black Sea. Sheki station was installed by the Institute of Geology and Geophysics of Azerbaijan National Academy of Sciences on the north-west of Azerbaijan (Fig. 1) and is surrounded by the seismogenic zones. It is located in the foothills of the Greater Caucasus at a height of 723 m, and represents the main Earth-tidal station in Azerbaijan.

The gravity data analyzed in our study span for 358 days from 2011:11:28:08:48 to 2012:05:11:05:11:59. The data are acquired by the automated Burris Gravity Meter B-14, provided by the company ZLS Corporation, Austin/Texas, USA (Fig.6). The sampling time was set at 3 min and date and time were in UTC. GPS was used for automatic time correction. The accuracy of the singular measurement accounts for nearly 1 μGal ▫ 10 nm/s2, which confirms the uniquely high precision of such equipment.

We analyzed the 3-min sampled data of Earth’s gravity field from November 28, 2011 until May 11, 2012. The data show a clear decreasing behavior. We firstly removed such linear non stationarity by fitting the data with a line by a least square method. Then we subtracted this line from the data. We explored the spectral properties of the detrended data by using the periodogram method. The results are shown in Fig. 7.

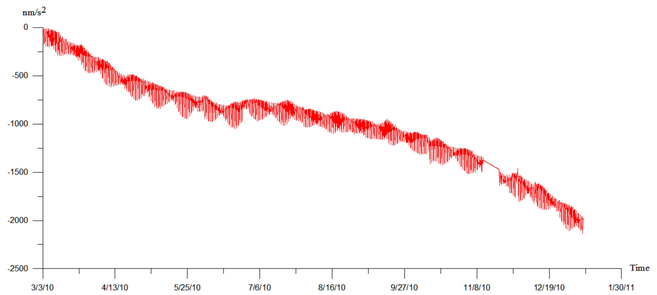


Figure 6. Earth’s gravity time series from 2011:11:28:08:48 to 2012:05:11:05:11:59 in Sheki station. The sampling time is 3 min.

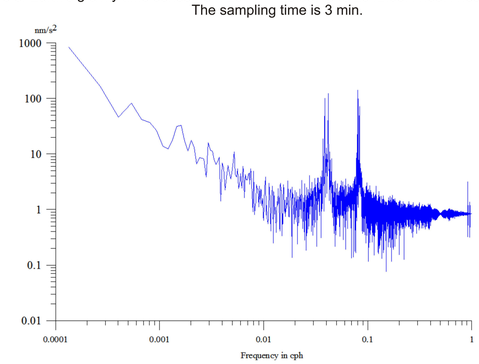


Figure 7. Periodogram of the detrended gravity data. The two oscillations at 24 h and 12 h are clearly visible. The higher amplitude of the 12-h periodicity respect to the 24-h cycle indicates that the 12-h periodicity is not a higher harmonic of the 24-h cycle.

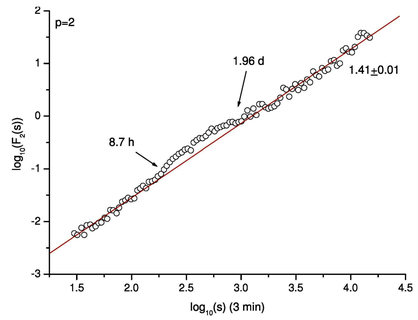


Figure 8. F2 (s) of the residual Earth’s gravity data, after removing the periodicities at 24 hours and 12 hours with p=2.

Between the timescales of about 8.7 h and 1.96 days, the fluctuation function shows an excess of variation with respect to the linear behavior. Increasing the value of the degree of the fitting polynomial, we observe that this effect is still present and the band of timescales in which the fluctuation function show such excess of variation seems to shift up and becomes even more definite. We could probably attribute the effect found in the fluctuation curve of our gravity signal to a possible superposition of a periodical trend on the gravity noise signal that were not removed just by applying the periodogram analysis.

Multifractals are principally characterized by high signal variability on a wide range of temporal scales, thus being depicted as intermittent with sudden bursts of high frequency fluctuations. We calculate the polynomial local trend for each of the segments by a least square fit of the series. Then the variance is calculated and averaged for over all segments to obtain the fluctuation function. If the scaling behavior of small fluctuations is different from that of the large ones then the generalized Hurst exponent depends on q and indicates that the series is multifractal. Multifractality in a series can be also quantified by using the singularity spectrum, obtained applying the Legendre transform. The multifractal spectrum gives information about the relative importance of various fractal exponents present in the series. In particular the width of the spectrum indicates the range of present exponents, so the larger the width more multifractal the series.

From [cpd]	To [cpd]	wave	amplitude nm/s²	amplitude factor	Standard deviation	phase lead [deg]	Standard deviation [deg]
0.501370	0.911390	Q1	66.94	1.135	0.008	1.84	0.43
0.911391	0.947991	O1	354.57	1.151	0.002	0.96	0.08
0.947992	0.981854	M1	28.23	1.166	0.016	-0.41	0.78
0.981855	0.998631	P1	161.07	1.124	0.004	-0.55	0.19
0.998632	1.001369	S1	17.58	5.194	0.229	77.60	2.53
1.001370	1.004107	K1	489.74	1.131	0.001	1.18	0.06
1.004108	1.006845	PSI1	10.76	3.176	0.155	-8.09	2.80
1.006846	1.023622	PHI1	8.77	1.422	0.087	20.12	3.50
1.0236230	1.057485	J1	26.88	1.110	0.021	7.41	1.11
1.057486	1.470243	OO1	15.09	1.139	0.030	5.25	1.51
1.470244	1.880264	2N2	15.61	1.201	0.031	8.62	1.47
1.880265	1.914128	N2	95.78	1.177	0.006	1.83	0.31
1.914129	1.950419	M2	498.03	1.171	0.001	1.30	0.06
1.950420	1.984282	L2	13.90	1.157	0.051	-6.19	2.55
1.984283	2.002736	S2	229.43	1.160	0.003	0.61	0.13
2.002737	2.451943	K2	60.62	1.128	0.009	2.81	0.47
2.451944	3.381478	M3	6.79	1.079	0.077	1.08	4.10
3.381379	4.347615	M4	0.63	7.322	5.476	57.38	42.85

Table 2. Adjusted tidal parameters

Conclusions

The gravity signal is mostly modulated by the 12-h and 24-h periodicities. Earth tides are deformation of the solid Earth’s body which occur under the influence of the gravitational fields of Sun and Moon. The 12-h and 24-h periodicities are those of tidal deformations of Earth, induced by the Sun and Moon. After removing these two intense periodicities, the residual signal is not purely random but shows a dynamical structure indicated by the power-law shape of the power spectrum with exponent around 1.7.

The analysis of the second order fluctuation function reveals that the signal shows an excess (with respect to the simple linear behavior) of fluctuation variation between about 9 h and 2 days. It is still not very clear the nature of such excess of fluctuation at these timescales; maybe a correlation with the Earth’s gravity field-triggered seismicity could be postulated.

The gravity signal appears multifractal and its multifractality depends on the long-range correlations rather than the probability density function of its values. These type of fluctations in tidal gravity data can be observed also after the underground and underwater nuclear explosion tests.

References

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