Tidal and Seiche signals on Baikal Lake level.

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Abstract

Study of Baikal Lake level variation was developed by pressure sensor with digital system. Observation point is located at Listvyanka (source of Angara river, Baikal Lake). Seasonal water level variations reach 0.8÷1.1 m. Tidal amplitudes reach 7.9 mm (M2), 5.6 mm (S2), 4.6 mm (O1), 6.8 mm (K1) and 20.9 mm (Mf). We discuss tidal and seiche models for Baikal Lake. The diurnal and semi-diurnal tides can be explained by a tidal oscillation of the southern basin of Baikal Lake along a direction 70°N..First mode of seiche has a period of 4.6 hour with an amplitude of 60 mm. We tried to observe these effects with GPS observations too. Snow-ice shield covers Baikal Lake (Eastern Siberia) during January-May period. Ice shield displacements studies have been performed during three Baikal-winter expeditions (February-March, 2006, 2007, 2008) with geodimeter and GPS receivers. Motion and breaking process of ice field was observed along long cracks between snow-ice blocks. Sizes of these objects were from 1 km to 20 km accross Baikal Lake. Fracturation and displacement process is connected with winds, currents, air pressure, temperature, earthquakes, seasonal level variations and snow-ice conditions at Baikal Lake. After these events eigen-frequencies of snow-ice fields was registered with periods from 1 minute to 5 minutes and with amplitude up to 12 mm. Model of blocks with elastico - viscous connections is well correlated with observed data for eigen-frequencies following growing crack process and allows to determine the Young modulus of the ice.

Key words: Baikal Lake level, tide and seiche, pressure sensor, GPS receiver, geodimeter, ice field motion, eigen-frequency of blocks.

1. Introduction

Baikal Lake is situated in central Asia between 51° 29’ and 55° 46’ N (Figures 1, 2). Baikal Lake covers an area of 31500 km^2. It is 636 km long and its width varies between 25 km and 80 km. The fresh water volume accumulated is 23000 km^3 and the coast line is 2000 km [Baikal Atlas, 1993]. Baikal Lake consists of south basin with maximal depth 1423 m, middle basin with maximal depth 1637 m and north part with maximal depth 890 m. Winter period at Baikal region lasts more than 180 days. Annual average temperature is -0.7 °C in southern part, -1.6 °C in central part and -3.3 °C for northern part. Snow covers Baikal region from October-November to April-May; thickness of snow reaches 1÷40 cm; maximal thickness can exceed 1 m in Mountain area at south-west and north-east of Baikal Lake. Ice covers Baikal Lake from December-January to May-June. Usual thickness for first decade of March is of 0.6÷1.0 m (Figure 1). Temperature and wind condition, circular currents in different Baikal basins and water level variation controls the typical configuration of ice cracks along coast line and accross Baikal Lake (Figure 1). Study of snow-ice plates velocity and brittle breaking on plate boundaries was the aim of two Baikal-winter expeditions [Dobretsov et al., 2007]. Another task was the study the tidal and seiche variations of Baikal Lake. We investigated tidal and seiche models for Baikal Lake.

2. Instruments and Method

Observation of water level was carried out at permanent station with pressure sensor, reaching a precision of 0.1 ÷ 2 mm level. Measurement of displacement of ice shield was developed by geodimeter and GPS technology. Two-frequency GPS receivers TRIMBLE-4700 and two-frequency geodimeter TOPAZ-SP2 were used for measurements [Goldin et al., 2005; Timofeev et al., 2006]. Geodimeter observation on 1 km base had precision level 1 ÷ 3 mm (usual reading 6 seconds) at summer condition. Experiment with geodimeter at -5°C ÷ -6°C (usual reading 12 ÷ 18 seconds) allowed to to reach a precision of 0.1 ÷ 0.5 mm (Talaya observatory, south-west of Baikal region, March-April 2005). Our GPS observation at Talaya observatory had been performed during 2000-2007 yy.. Using calculation by Gamit-GLOBK and GPSurvey programs for this point were received 1 ÷ 2 mm/y velocity to the East and seasonal variation of Talaya - Irkutsk line (76 km) with double amplitude 5 mm. During the Altai and Baikal campaigns we used hard benchmarks for our instrument. At Baikal Lake experiment equipment's tripods were frozen to snow-ice plate.

3. Ice plates relative motion

First winter expedition on Baikal Lake took place during the third decade of February 2006. Temperature condition from 22/02 to 26/02 were -12°C ÷ -20°C at day period and -20°C ÷ -26°C at night (minimum -26°C during 25 ÷ 26/02 night). Wind's conditions were changeable during the week. East-wind was blowing from 22 to 24/02 and S-E wind from 25 to 26/02 with a speed 1 ÷ 5 m/sec. Geodimeter polygon was located on different plates separated by big cracks (Figure 1, 2, 3). Distance to the lake coast was 3 km, and 6km to Listvyanka (the source of Angara river). During the campaign geodimeter measurements were performed at day time only. Changes along crack (base – reflector 1) from 314,513 m to 314,575 m were observed during 100 hours (22 ÷ 26/02). Cross line (base – reflector 2) changed up 120 mm during the same period. The trajectory of relative plate motion is presented at Figure 3. The duration of separate measurement was limited by temperature-wind condition and by the capacity of the battery (Figure 4). Only on

25/02/2006 three observation lines were monitored (Figure 3). The measured strain reached $2\cdot10^{-4}$ during the 8 hours observation period. Breaking ice process happened usually at night (10^{-3} strain level) and was accompanied by sound effect. The development of breaking process at day period is presented on Figure 4. This process had three stages. First stage - extension motion during two hours, second stage – shift plate motion along crack during three hours, third stage - breaking of ice with “natural frequency oscillations” and reverse motion. Oscillation on Natural frequencies after growing crack is presented on Figure 4. We had three periods of free oscillation – 0.8, 2 and 5 minutes. Viscosity of the ice was estimated by the delay curve: $10^{11} \div 10^{12}$ Pa·s.

1D model of three blocks with elastic - viscous connections [Figure 6, Medvedev, 2006; Nur, 1977] are close to observed data (Figure 5). Motion equations for three masses system with characteristic’s equations are presented below:

$$\ddot{\xi} + 2b\dot{\xi}_1 + \omega_0^2(2-\Delta k/k)\xi_1 - \omega_0^2\xi_2 = 0$$

$$\ddot{\xi}_2 + 2b\dot{\xi} + 2\xi_2 - \omega_0^2(\xi_1 + \xi_3) = 0$$

$$\ddot{\xi}_3 + 2b\dot{\xi}_3 + \omega_0^2(2-\Delta k/k)\xi_3 - \omega_0^2\xi_2 = 0$$

$$\Delta k = k - k_1$$

$$\omega_0^2 = k/m$$

$$\lambda_{1,2} = -b \pm i\omega_0\sqrt{(2-\frac{\Delta k}{2k}) - \sqrt{2 + (\frac{\Delta k}{2k})^2 - \frac{b^2}{\omega^2}}} = -b \pm i\omega_1,$$

$$\lambda_{3,4} = -b \pm i\omega_0\sqrt{(2-\frac{\Delta k}{2k}) - \frac{b^2}{\omega^2}} = -b \pm i\omega_2,$$

$$\lambda_{5,6} = -b \pm i\omega_0\sqrt{(2-\frac{\Delta k}{2k}) + \sqrt{2 + (\frac{\Delta k}{2k})^2 - \frac{b^2}{\omega^2}}} = -b \pm i\omega_3.$$

where ξ_i – shift of i-mass from equilibrium position; m – block mass; k and k1 - elastic parameters (block 1 – block 2; block2 – coast); b – viscosity parameter, delay coefficient; ω_o – natural frequency.

When we have simple conditions (k = k1 and b – small) and use frequencies from our experiment - ω_o = 0.1 rad/sec. We made elastic modulus determination and energy estimation for ice breaking process in the frame of model for blocks with elastico - viscous connections (Figure 6).

Elastic modulus for ice: we have ice plates with dimensions l · w · h and density ρ.

Let us express the force F required to shift the ice plate on the distance Δx:

$F_\sigma = S \cdot \sigma = h \cdot w \cdot E\,(\Delta x / l)$, with E – Young module, σ - stress.

On other side the same elastic force can be written as:

$F_e = k \cdot \Delta x$, with k rigidity of harmonic oscillator with pulsation $\omega_0^2 = k / m$ (Figure 6).

From balance of power: $F_\sigma = F_e$, or

$$h \cdot w \cdot E\,(\Delta x / l) = k \cdot \Delta x,$$

As $k = m \cdot \omega_0^2$, $m = \rho \cdot h \cdot w \cdot l$,
we have for Young modulus:

$$E = \rho \cdot l^2 \cdot \omega_0^2$$

With $\rho = 0.92 \cdot 10^3$ kg/m^3, $l = 10^4 \div 4 \cdot 10^4$ m, $\omega_0 = 0.1$ rad/sec
We get $E = 10^9 \div 1.4 \cdot 10^{10}$ Pa

Energy estimation for ice plate system was developed as follows:
Let us consider a rectangular ice block with dimensions l, w and h and density $\rho = 0.92 \cdot 10^3$ kg/m^3,
volume V=h.w.l, mass $m = \rho \cdot h \cdot r \cdot l$, velocity $V_0 \approx 1$ mm/s [Kingery, 1963; Kouraev et al., 2007; Pounder, 1965] The cinetic energy $W_0 = m \cdot V_0^2 / 2$.
For $l = 10^4$ m, $w = 10^4$ m, h = 0.7 m we get $W_0 = .310^5$ J. It is less than an earthquake of magnitude M=1
For $l = 4 \cdot 10^4$ m, $w = 4 \cdot 10^4$ m, h = 0.7 m we get $W_0 = 510^5$ J. It is close to an earthquake with M=1

4. Plate displacement relative to Baikal coast

During the 2007 winter expedition we continued motion investigation. Start of this expedition was shifted to first decade of March as temperature-ice condition was different. We had a strong winter in 2006 (very cold January-February period with -30°C during the day) with ice thickness 0.7 ÷ 0.9 m during the third decade of February. In 2007 January-February period was warm with -10°C during the day. Only at first decade of March ice thickness reached 0.4 ÷ 0.6 m but we had strong condition during this decade (day temperature -15°C ÷ -25°C and wind up to 15 ÷ 25 m/sec). Weather allowed only to use the GPS method (Figure 2). Calculation of 3D displacement relative IGS IRKT station (Irkutsk) is presented on Figure 7. This period differed from last year not only by weather condition but by earthquake activity too. Earthquake process in Baikal basin was absent during 2006-expedition, but two earthquakes happened during 2007-expedition (Figure 2 and Figure 7). Our polygon situated near N-S crack at 3 km from coast and 3 km from Listvyanka. During 4 ÷ 10 March there was active ice breaking process and a more strong one during 7 ÷ 8 March night. 3D snow-ice plate trajectory reflected Baikal earthquake process (4 ÷ 5 March) and 0.5 m trust from West at 7 ÷ 8 March. These two features were present on seismograms recorded at Talaya station (TLY). Ice breaking process is the cause of increased noise for seismology in Baikal area during January-May period (see section 3).

5. Tides and seiche at Baikal Lake

Processing of GPS data obtained during 2007 campaign allows us to separate the daily variation on vertical displacement of ice shield (Figure 8). The 2008 expedition (Figure 9) seeks after different goals. Tidal process, seiche and ice blocks displacement were investigated. Water level variation observed by pressure sensor with digital system was studied too. Displacement of ice blocks presented at Figure 10. Tidal and seiche variations are shown on Figure 11 and 12. Famous results were obtained for Lakes Baikal and Tanganyika, which have been studied accurately, in order to reveal the existence of Earth tides. Record of the levels obtained at two points on Lake Baikal have been analyzed at different times by Sterneck, Grace, Ekimov and Krawetz, Parfianovitch and Aksentieva and have provided the following numerical values [Melchior, 1983, 1992]:

Petchanaia (52° 15’ N 105° 43’ E)		Sterneck	$\gamma = 0.52$	$\varphi = -3°$
	Wave M2	Grace	$\gamma = 0.54$	
		Aksentieva	$\gamma = 0.72$	$\varphi = +1°$
	Wave K1	Sterneck	$\gamma = 0.73$	$\varphi = +4°$
Tankoi	Wave M2	Aksentieva	$\gamma = 0.55$	$\varphi = +27°$

The amplitudes are of about 5-6 mm.

Analog of Baikal Lake is Lake Tanganyika (Albertville). The observations were made at Albertville, where the lake is about 75 km wide. The median position of Albertville is such that the level there is insensible to the uninodal longitudinal seiches whose period is about 4 h (length of Lake 638 km, mean depth 800 m), on the other hand the binodal longitudinal seiche (period 2 h) and the uninodal transverse seiche (period 40 min) should be observable. Taking into account the short period of the free oscillations, we can treat the problem of the luni-solar tides by the static theory. The M2 amplitude is about 1.5 mm. As the width of the lake is 72km the EW tidal oscillation is

Albertville	Wave M2	Melchior	$\gamma = 0.55$	$\varphi = 9°$

For Baikal region we have normal tidal gravimetric and clinometric factors [Ducarme et.al., 2008, 2004, 2006; Timofeev et al., 2006b, 2008; Dehant et al., 1999]. Applying HICUM analysis method [Van Ruymbeke et al., 2001] on water level data at station Listvyanka (Figure 13) we estimated the amplitude of the main tidal waves: from 7.8 ÷ 7.9 mm for M2 to 20.9 mm for Mf wave (Figure 14) and from 4.3 ÷ 4.6 mm for O1 to 6.38 ÷ 6.9 for K1 (Figure 15). For the diurnal and semi-diurnal tides the total amplitude reaches a few centimeters. It is certainly not the static equilibrium tide which reaches a few decimeters. We tried first to model the signal by ETERNA tidal analysis method [Wenzel, 1996]. In Table 1 the observations seem to fit quite well a tilt in EW direction. However the phase lag for M_2 and the other main waves is still large and the fit is better when we use the azimuth “70°N” (Table 2). We can thus model the tidal effect as a tilt of Lake Baikal surface in the azimuth 70°N: There is a straightforward relation between the vertical tidal displacement Δr and the tilt of the surface ε [Melchior, 1983,ch.8]

$$\Delta r=(L/2).\sin\varepsilon$$

$$\varepsilon(rad)= 2\Delta r/L$$

where L is the width of the lake in the given azimuth. For the wave M2 we observe a vertical displacement of 7.964mm. The corresponding tilt of the vertical is

$$\varepsilon= A_{th} *\gamma_{th}$$

The astronomical amplitude A_{th} (9.544mas) for a rigid Earth is modulated by the elastic response of the Earth expressed through the amplitude factor $\gamma_{th} = 1 + k - h = 0.69125$. This theoretical value is confirmed by the results obtained at the Talaya observatory (γ_{NS}.= 0.704 and γ_{EW} = 0.710; Timofeev et al., 2008). We get thus ε(mas)=6.597 and ε(rad)= 31.98 nanorad. Inserting these values in the relation

$$L=2\Delta r/\varepsilon(rad)$$

We get L=498km. Similar computations provide L=412km for S2, L=420km for O1 and L=440km for K1.These values are compatible with the total length of the southern and central basins of the lake from Slyudyanka in SW to Ust Barguzin in NE. This line is more or less oriented in the correct azimuth (Figure 16). The tidal tilt is symmetric around the ridge separating the two basins, where the tidal amplitude vanishes. The Northern basin oriented more in the NS direction should be a priori decoupled. However The above equation is written under the assumption that the tidal amplitude is equal to zero in the middle of the lake, as in the example given above for Lake Tanganyka, which has a very simple shape and NS orientation. In the case of Lake Baikal the southern basin where the observations take place is separated from the central one by a ridge and both basins could oscillate independently, provided that tides vanishes at the limit of the two basins. Then L will be the length of the southern basin and the relation becomes

$$L=\Delta r/\varepsilon(rad)$$

providing values ranging from 206km to 249km in rough agreement with the size of the southern basin. Further studies are required to get firm conclusions.
The fortnightly Mf tide has an amplitude similar to the equilibrium tide and is certainly generated by a completely different mechanism.

When we cut off tidal effect from water level records the seiche variation is clearly seen (Figure 17). Seiche have periods: 4h 33 m, 2 h 33 m, 1 h 28m, 1h 06 m at Listvyanka point. Zero lines for seiches are situated at distance 280 km, 130 km, 360 km, 540 km respectively from southern point of Lake (Kyultyuk).

Theoretical seiche periods presented in relation

$T = 2l / (n\sqrt{gh})$,

where l – length of the lake, h – average depth of the lake, g = 9.8 m/c^2 and n – number of knots (modes). For first seiche with period 4.6 h we have the depth 630 m.

Seiche amplitude has seasonal variation (Figure 18). The origin of seiches is connected with earthquakes, air pressure variation and with tides. First seiche (4h 38.4 min) is extremely well recorded at Listvyanka point as well in water level, as in ice displacement.

6. Conclusions

Study of Baikal Lake level variation was performed using pressure sensor with digital recording located at Listvyanka (source of Angara river) and GPS observations on Baikal ice. Ice shield displacements had been performed during three Baikal-winter expeditions (February-March, 2006, 2007, 2008) with geodimeter and GPS receivers. Seasonal water level variation are observed at 0.8

m ÷1.1 m level. Tidal amplitude may reach 7.9 mm (M2 wave), 3.5 mm ÷ 6.7 mm (O1 and K1) and 20.9 mm (Mf) at Listvyanka. The diurnal and semi-diurnal tides can be explained by a tidal oscillation of the southern basin along a direction 70°N. First mode of seiche fluctuation has a period 4.6 hour with double amplitude 60 mm (February-March). Origin of seiche is connected with earthquakes, air pressure variation and tides. Motion and breaking process of ice shield system was studied along cracks between ice fields. Eigen-frequencies of ice blocks was registered with periods from 1 minute to 5 minutes and with double amplitude up to 12 mm. Model of blocks with elastico - viscous connections were close to observed data for eigen-frequencies after growing crack process. Young's modulus for the ice was determined from a one-dimension model as $E = 7\cdot10^9$ Pa. Viscosity of the ice was estimated from the delay curve to $10^{11} \div 10^{12}$ Pa·s.

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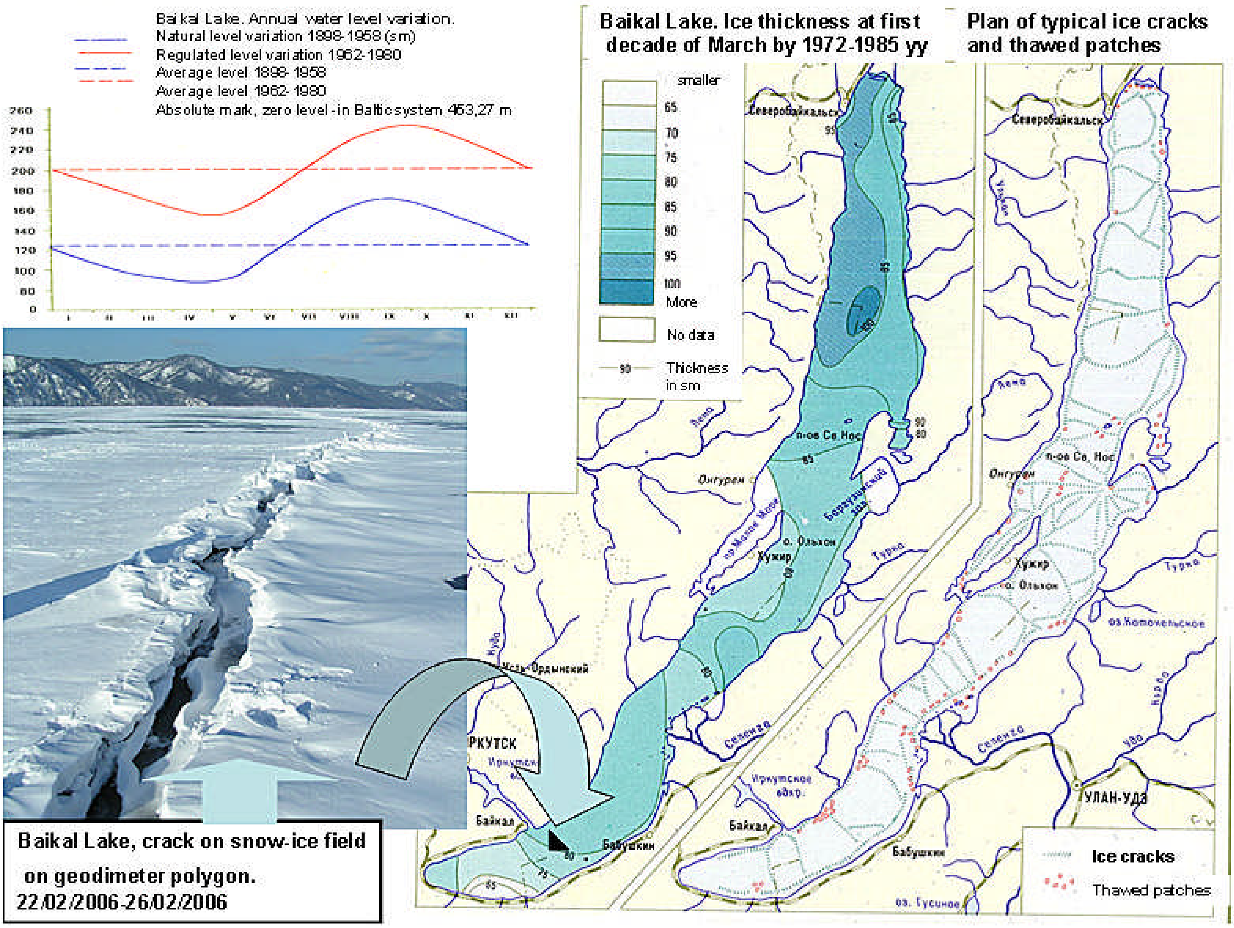


Fig. 1. Left slide – Baikal Lake, annual water level variation, before and after construction of Irkutsk power station;

– ice crack.

Right slide – Location of geodimeter polygon on snow-ice field;

– Map of ice thickness at first decade of March by 1972-1985 data;

– Sketch of typical ice cracks and thawed patches [Baikal Atlas, 1993].

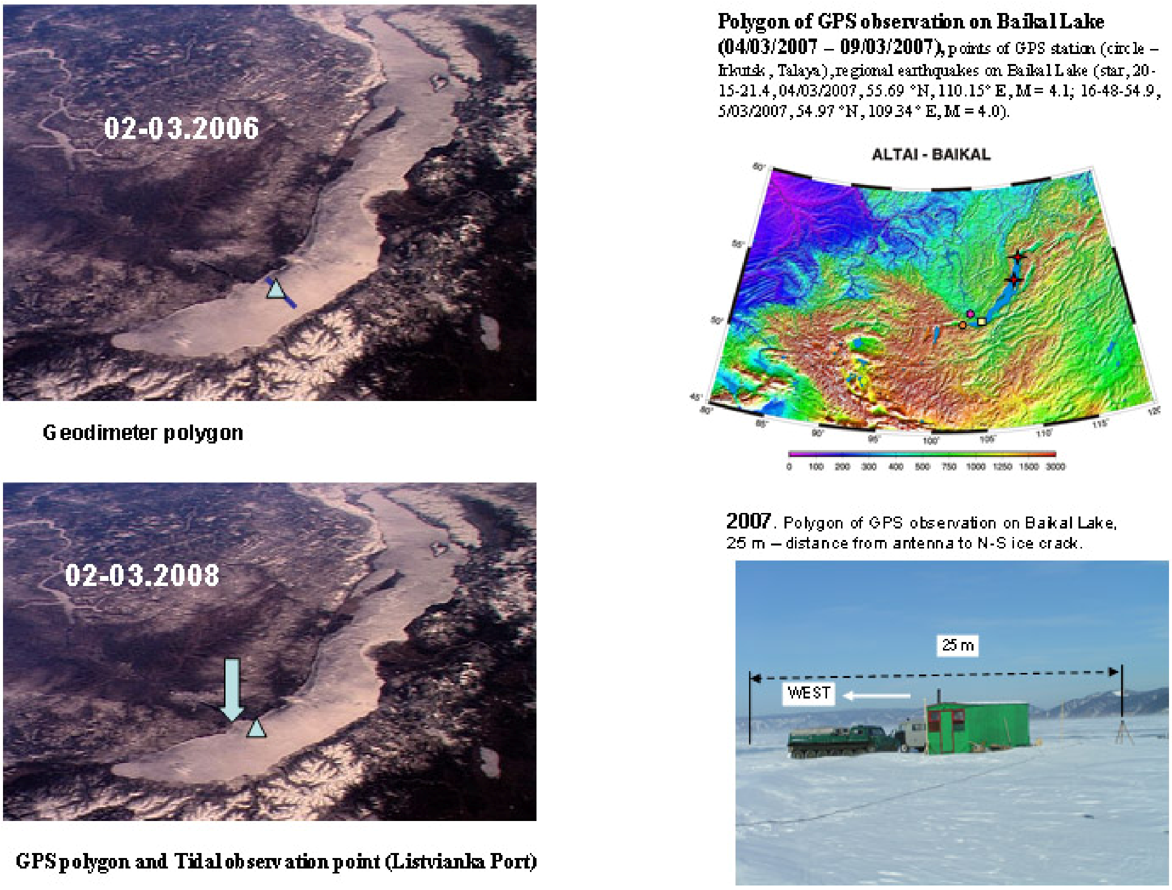
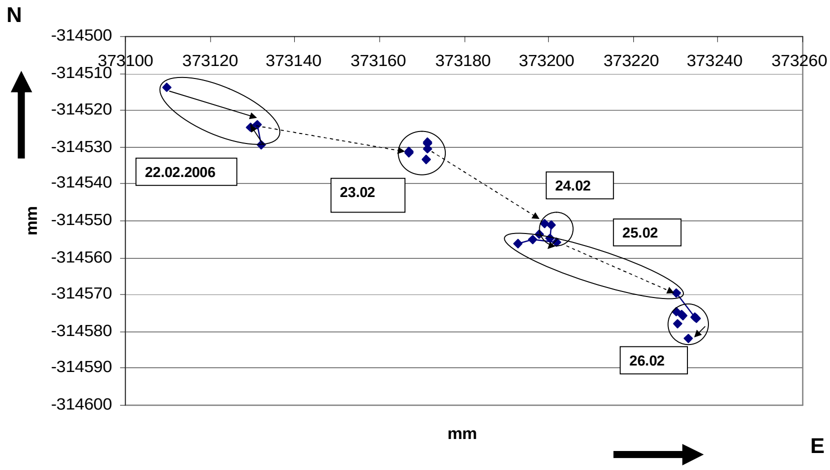


Figure 2. 2006-2008 expeditions on Baikal Lake.



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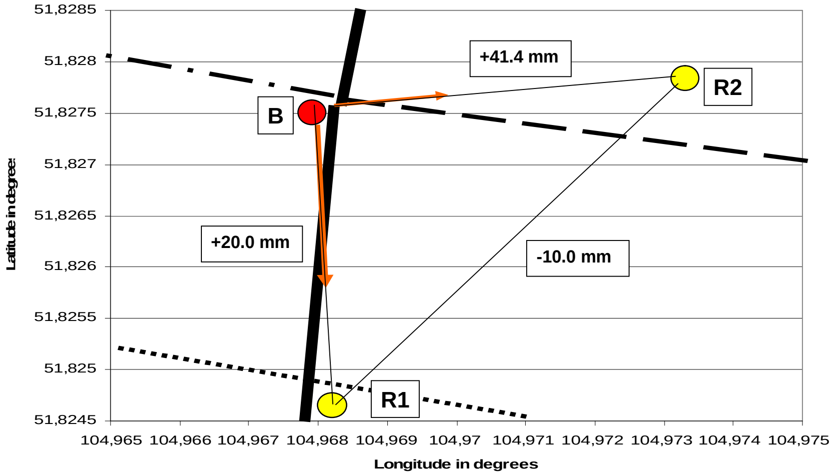
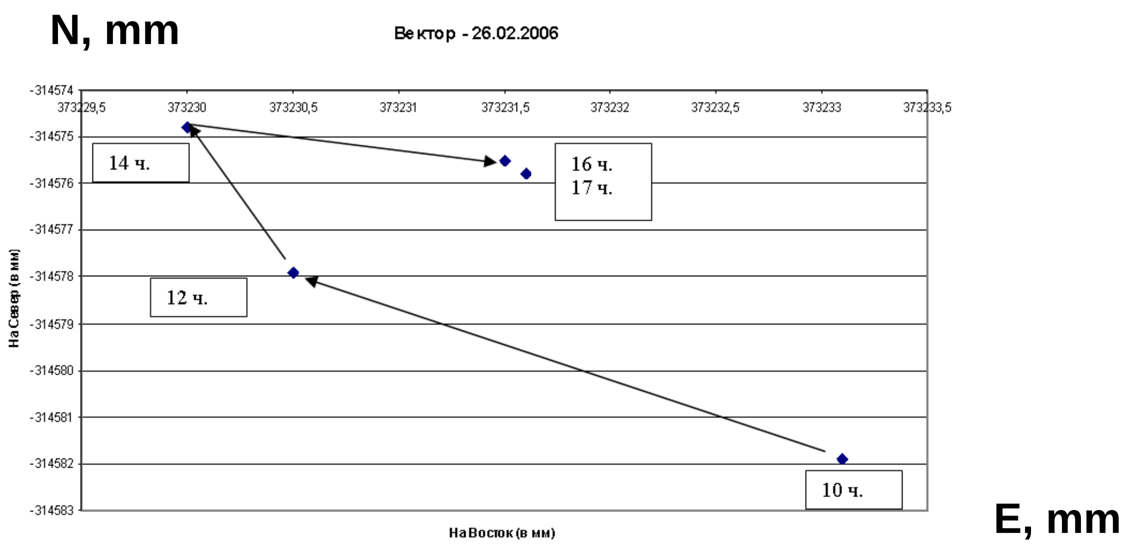


b)

Figure 3. a) Horizontal vector diagram by geodimeter data **from 22.02.2006 to 26.02.2006**

b) Geodimeter polygon (B-R1 = 314 m, B-R2 = 373 m, R1-R2 = 499 m), B – base, R1 and R2 – reflectors, solid line – main crack with shift-extension motion, interrupted line – trust zones. Change of lines from 10h to 18h **25/02/2006.** Values and orientation of main strain axes: compression $-0.2 \cdot 10^{-4}$, 38.1°N; extension $+1.9 \cdot 10^{-4}$.



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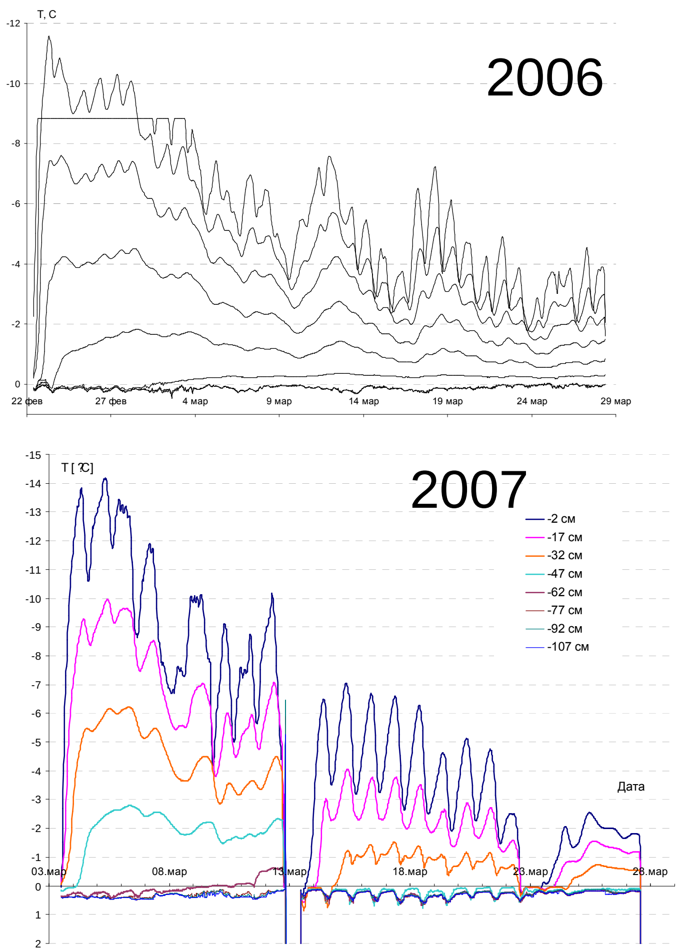
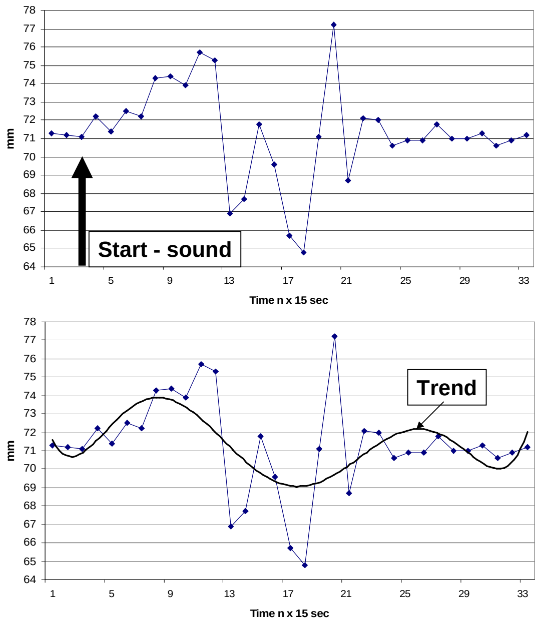


b)

Figure 4. a) Daily displacement of ice fields by geodimeter measurement from 10 h (L.T.) to 17 h 26.02.2006. 14 h – sound of breaking ice. Temperature: -26 degrees at night, -11 degrees (day), East wind, at evening – SW wind.

b) Daily temperature variation at different ice depths.



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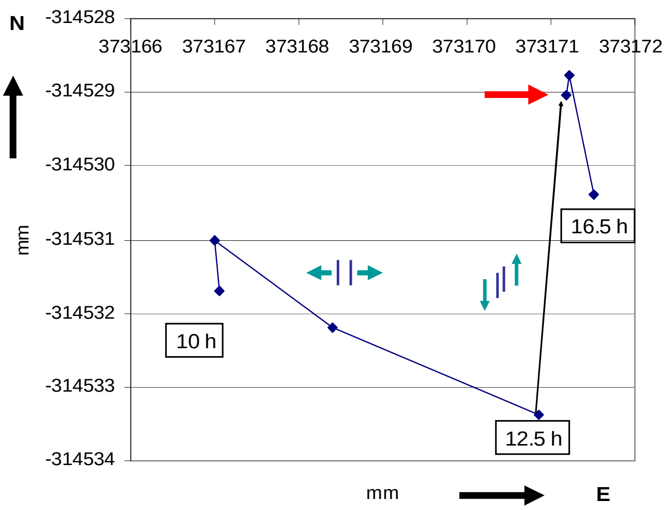


b)

Figure 5. a) Natural source of free oscillation and trend with delay. Line EAST [L(t) – 373100] mm, from 15h 17m to 15h 26m 23/02/2006. Double amplitude up to 12 mm.

b) Ice blocks relative motion. Horizontal displacement by geodimeter data from 10 h to 16.5 h (L.T.) **23/02/2006.** Arrow – moment of ice braking (sound). Night temperature -24 °C, day temperature -16 °C, wind – West.

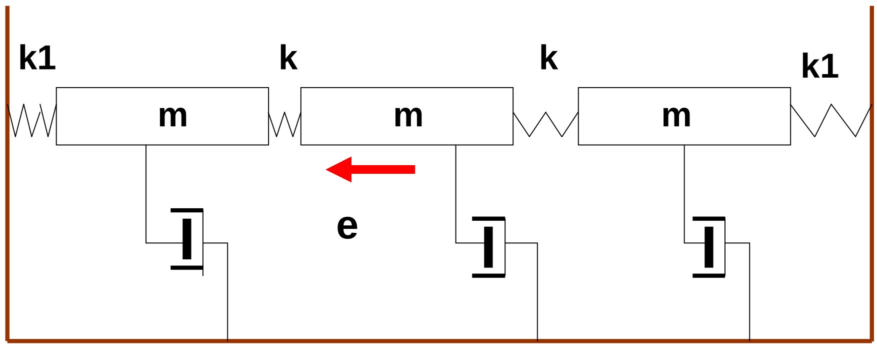


Figure 6. Model for blocks with elastico - viscous connections.

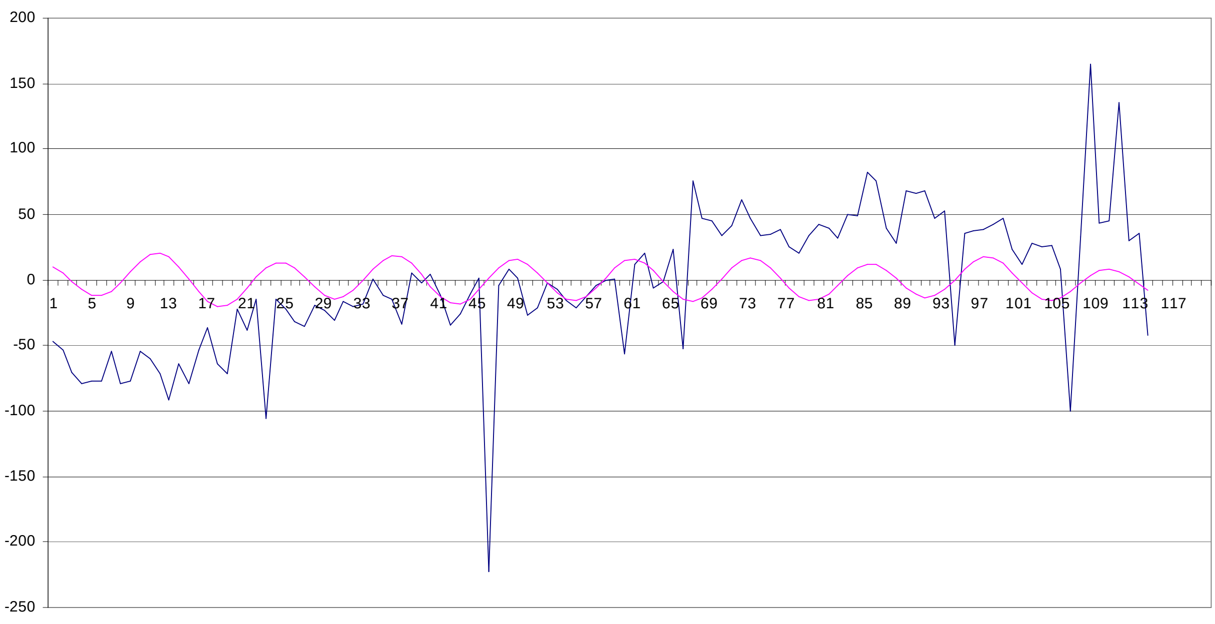
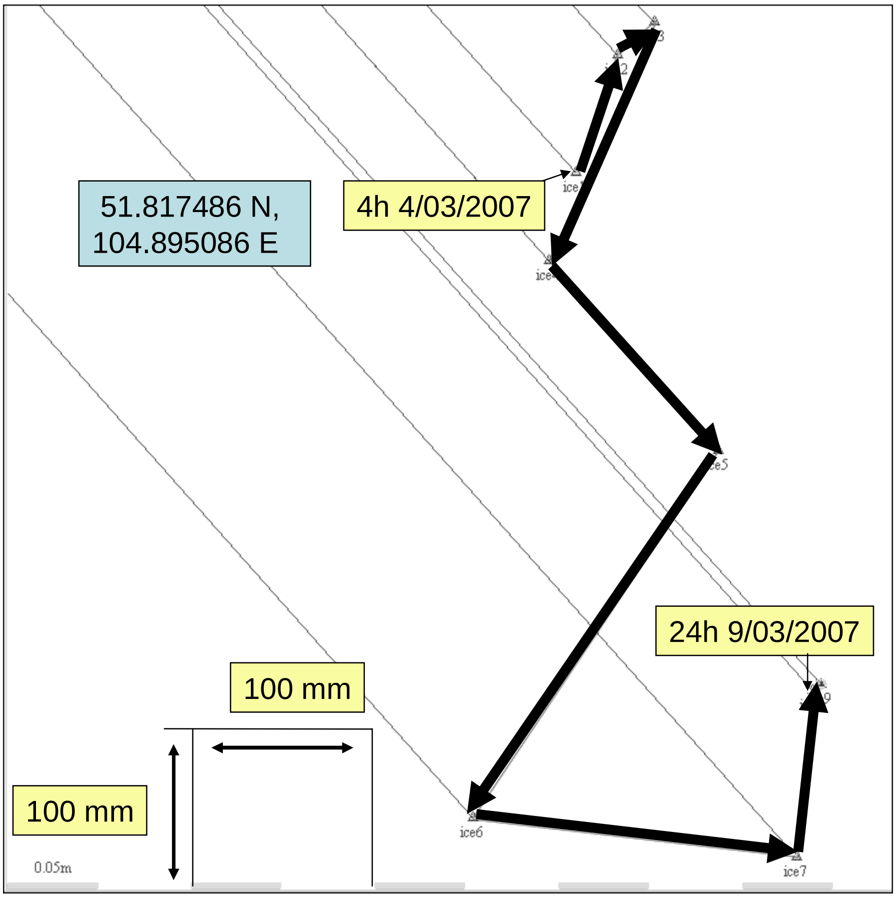


Figure 8. Vertical displacement by GPS 05.03.-08.03.2007



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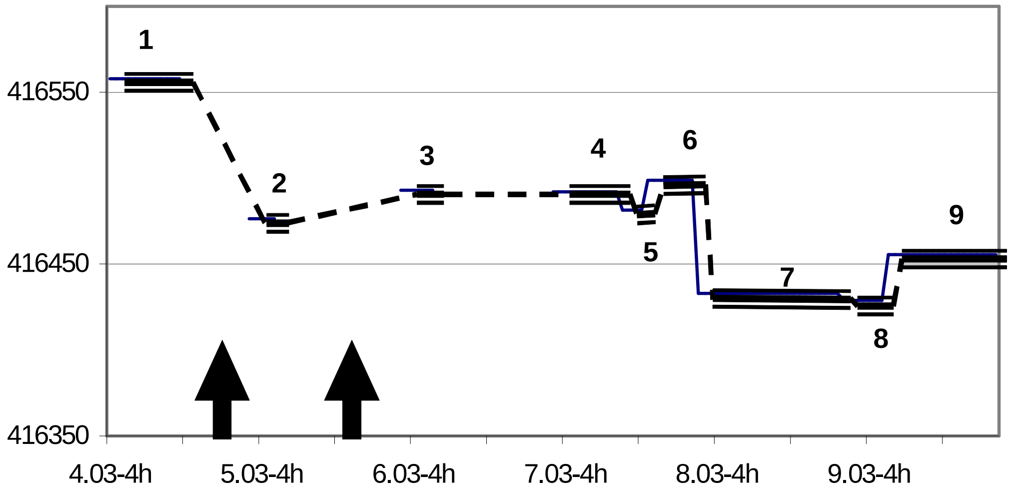


b)

Figure 7. Result of GPS observation - horizontal (a) and vertical (b, mm) displacements of ice plate from 04h 04/03/2007 to 24h 09/03/2007 (U.T., L.T. +8h). Calculation relative IRKT (Irkutsk) GPS station. Arrows – moments of regional earthquakes on Baikal Lake (20-15-21.4, 4.03.2007, 55.69 °N, 110.15° E, M = 4.1; 16-48-54.9, 5.03.2007, 54.97 °N, 109.34° E, M = 4.0). Moment “6-7” (night 7/03-8/03/2007) - brittle-breaking of ice – thrust motion from west (0.5 m thrust on ice plate). Subsidence 0.05 m was recorded at 25 m distance from crack line.

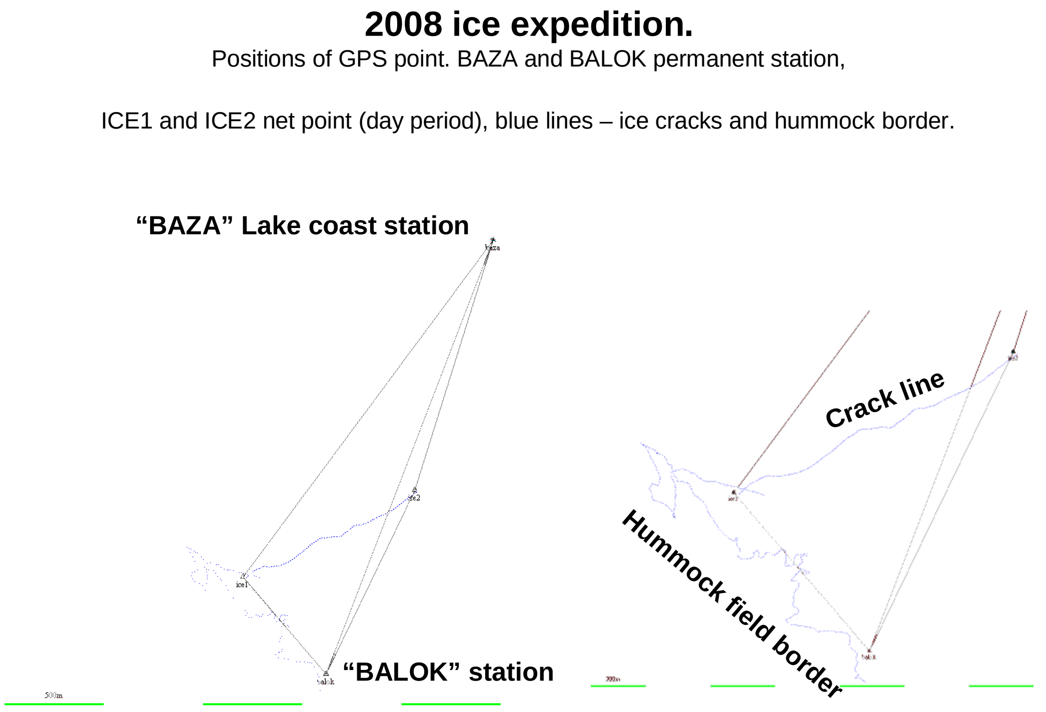


Figure 9. Positions of GPS points during. 2008 ice expedition.

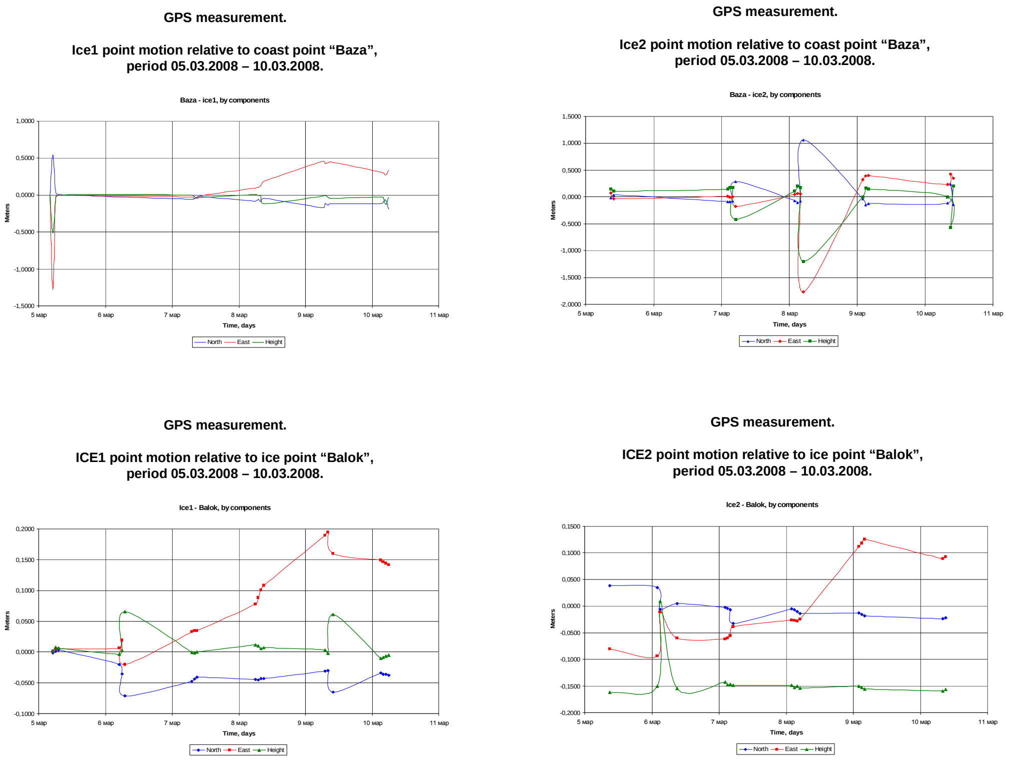


Figure 10. GPS measurement. 2008.

Figure 11. GPS measurement. Ice point “Balok” motion relative to coast point “Baza”, 12 h 06.03.2008 – 00h 08.03.2008. Seiche have 4÷5 h period.

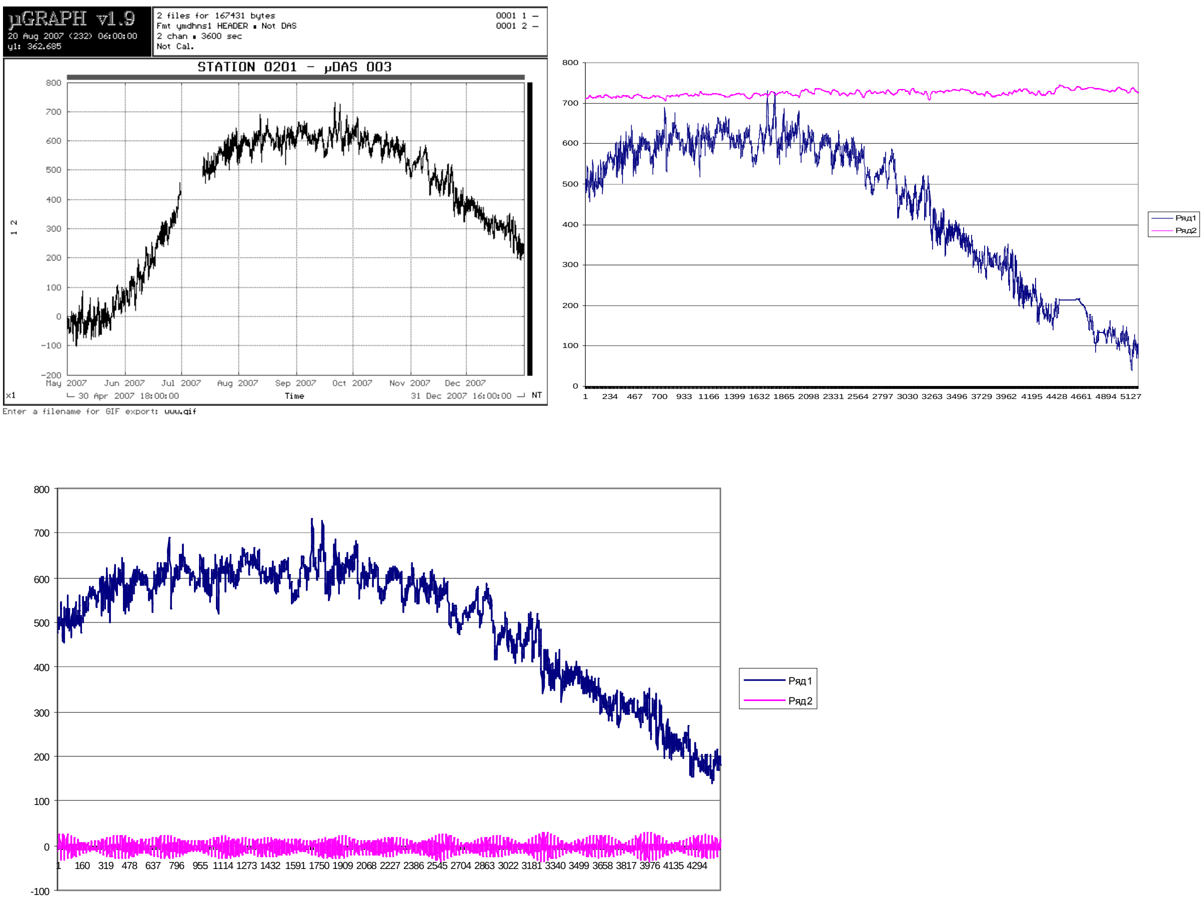
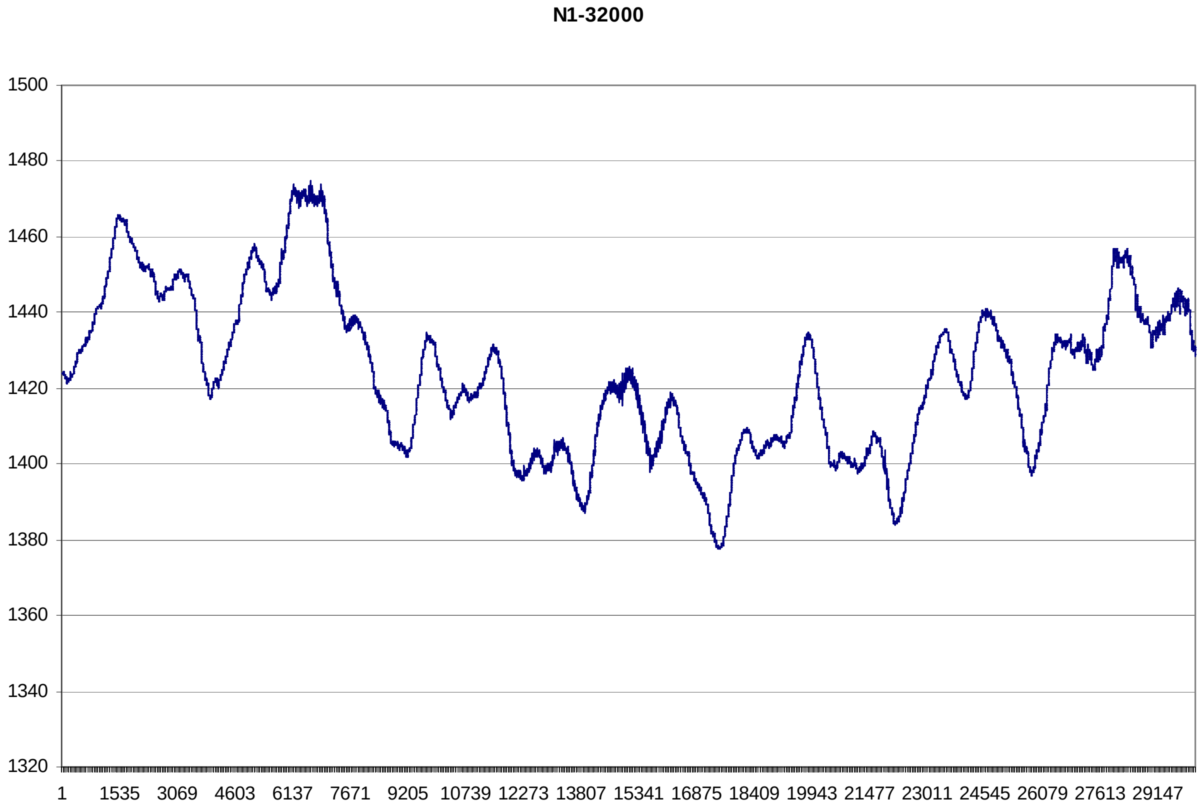


Figure 13.left: Baikal water level (mm) period from 19h 30.04.2007 to 16h 31.12.2007 (Annual variation 0.8 m) Right:Baikal water level (1) and air pressure variation (2), period from 10h 12.07.2007 to 18h 12.02.2008. Bottom:Baikal water level (1, mm) and theoretical tidal curve (2), period from 10h 12.07.2007 to 23h 12.01.2008



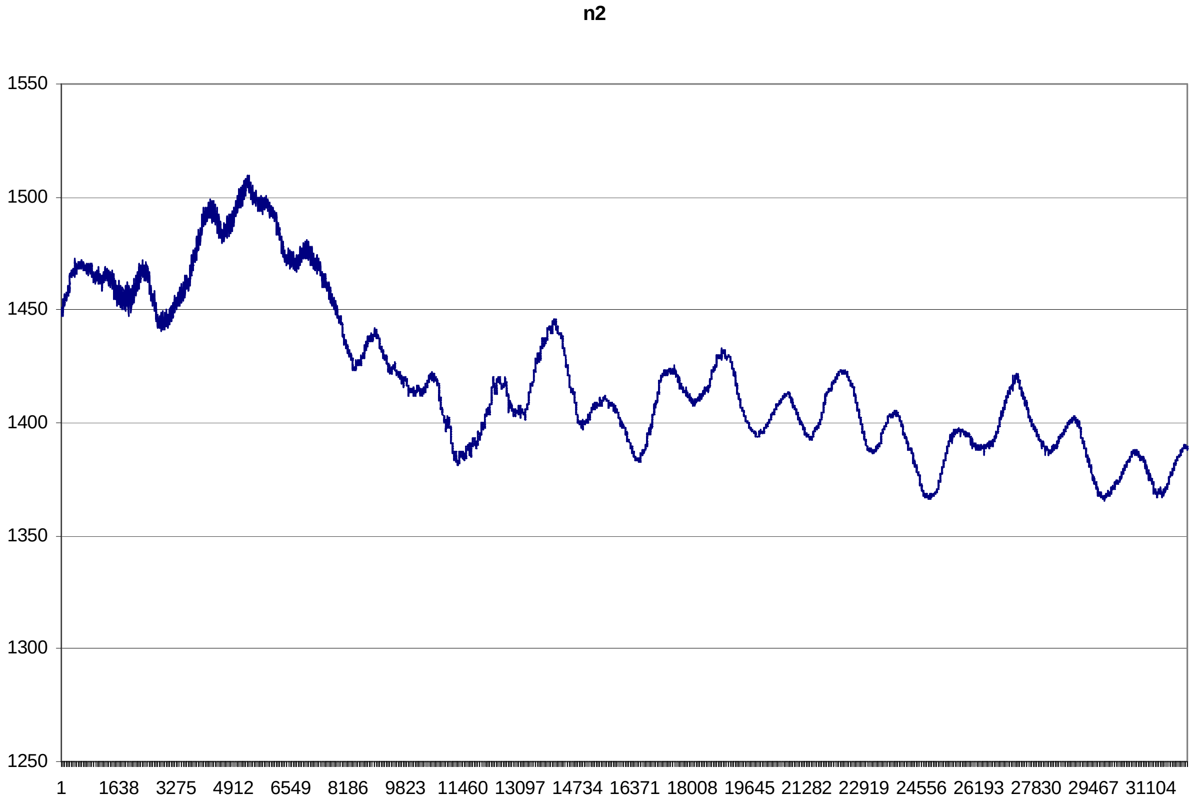


Figure 12. Baikal water level in mm. Point Listvyanka (10 sec. data). Tidal and seiche signals.

Top – from 21h 54m 44s 18.02.2008 to 09h 14m 34 s 22.02.2008.

Bottom – from 14h 47m 54s 22.02.2008 to 07h 41m 54 s 26.02.2008.

Tidal analysis by HICUM, water level in mm, different periods, amplitude for M2: 7.849; 7.793; 7.968 (by ETERNA: 7.964 mm), amplitude for Mf: 20.92 mm.

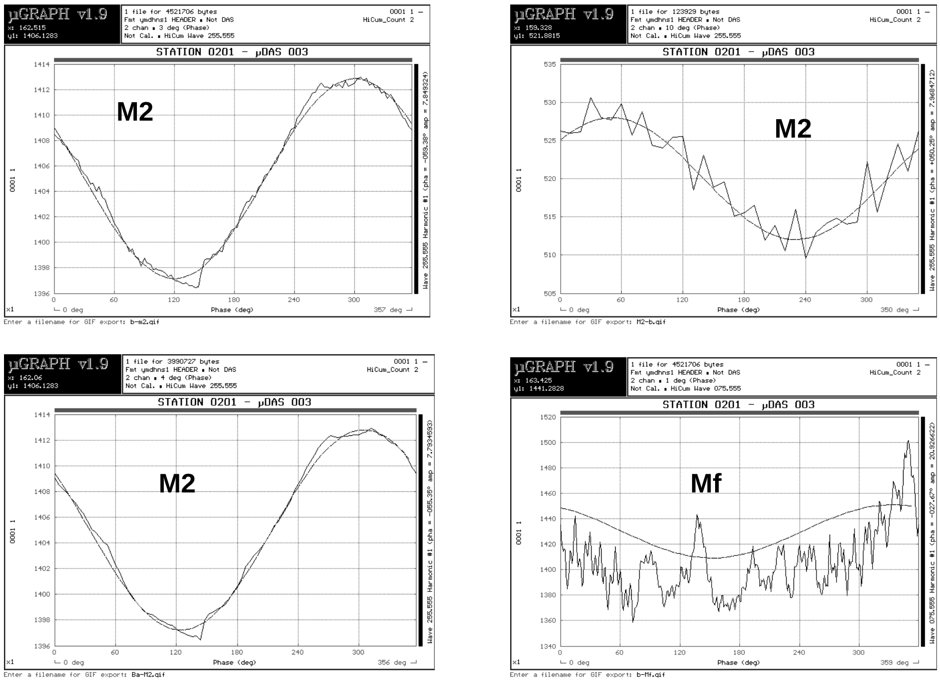


Figure 14. Tidal analysis by HICUM, water level in mm, different periods, amplitude for M2: 7.849; 7.793; 7.968 (by ETERNA: 7.964 mm), amplitude for Mf: 20.92 mm.

Tidal analysis by HICUM, water level in mm, different periods, amplitude for O1: 4.312; 4.639 (by ETERNA: 3.441 mm), amplitude for K1: 6.326; 6.877 mm.

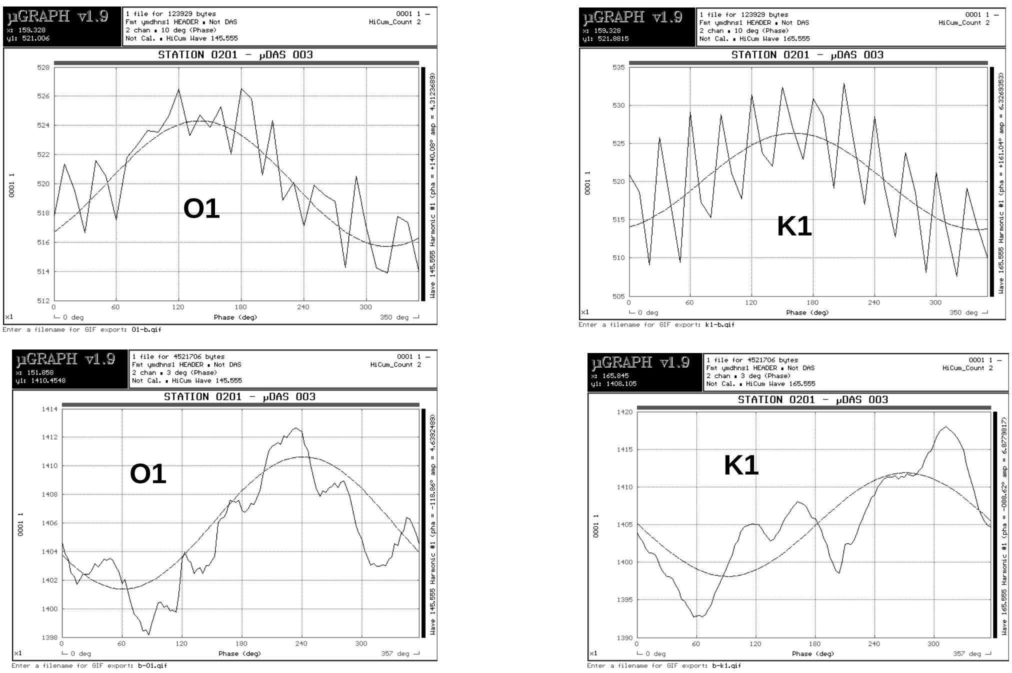


Figure 15. Tidal analysis by HICUM, water level in mm, different periods, amplitude for O1: 4.312; 4.639 (by ETERNA: 3.441 mm), amplitude for K1: 6.326; 6.877 mm.

Table 1. Baikal Lake water level tidal analysis by ETERNA (282 d.).

- Summary of observation data :
- 20070428100000...20070430160000 20070430180000...20070630160000
- 20070712100000...20080212180000 20080302 70000...20080305150000
- Initial epoch for tidal force : 2007. 4. 1. 0
- Number of recorded days in total : **282.00**
- CTED 1973 tidal potential used.
- UNITY window used for least squares adjustment.
- Numerical filter is PERTZEV 1959 with 51 coefficients.
- Estimation of noise by least squares method.
- Influence of autocorrelation not considered.
- Adjusted tidal parameters :

from	to	wave	ampl. [mm]	signal / noise	ampl.fac .	stdv.	phase lead [deg]	stdv. [deg]
286	428	Q1	0.652	5.2	0.66478	0.12691	-21.9829	7.2613
429	488	O1	3.442	26.6	0.67226	0.02528	13.0524	1.4485
489	537	M1	0.580	4.7	1.44160	0.30901	152.4077	17.7093
538	592	P1S1K1	4.532	35.9	0.62931	0.01755	19.3486	0.9961
593	634	J1	0.059	0.5	0.14763	0.29846	-57.6169	17.1020
635	736	OO1	0.290	3.2	1.31331	0.40871	18.6890	23.4445
737	839	2N2	0.270	2.4	0.90539	0.37681	39.5130	21.5894
840	890	N2	1.238	8.6	0.66200	0.07715	9.4261	4.4206
891	947	**M2**	**7.962**	51.7	**0.81537**	0.01578	**13.7928**	0.9042
948	987	L2	0.362	1.6	1.31082	0.83903	-23.6227	48.0790
988	1121	S2K2	3.562	24.0	0.78405	0.03268	26.0271	1.8774
1122	1214	M3	0.203	1.4	1.71064	1.23609	13.8662	70.8114

- Standard deviation of weight unit: 8.563
- degree of freedom: 6543
- Adjusted meteorological or hydrological parameters:
- no. regr.coeff. stdv. parameter unit
- 1 6.91506 0.14803 mas /

- Version ETERNA (1) ”tilt” in **90** degrees direction

Table 2. Tidal analysis by ETERNA used tilt version in 70° direction, water level in mm, air pressure – mm. p. p.. Period 28.04.2007 – 05.03.2008.

- Summary of observation data :
- 20070428100000...20070430160000
- 20070430180000...20070630160000
- 20070712100000...20080212180000 20080302
- 70000...20080305150000
- Initial epoch for tidal force : 2007. 4. 1. 0
- Number of recorded days in total : 282.00
- CTED 1973 tidal potential used.
- UNITY window used for least squares adjustment.
- Numerical filter is PERTZEV 1959 with 51 coefficients.
- Estimation of noise by least squares method.
- Influence of autocorrelation not considered.
- Adjusted tidal parameters :

from	to	wave	ampl. [mm]	signal / noise	ampl.fac .	stdv.	phase lead [deg]	stdv. [deg]
286	428	Q1	0.648	5.3	0.69969	0.13317	-27.8557	7.6228
429	488	O1	3.441	26.6	0.71091	0.02673	6.8399	1.5308
489	537	M1	0.616	4.7	1.61880	0.34300	144.8911	19.6561
538	592	P1S1K1	4.533	35.9	0.66591	0.01857	13.1618	1.0538
593	634	J1	0.063	0.5	0.16602	0.32352	-64.3833	18.5353
635	736	OO1	0.292	3.2	1.39926	0.43485	12.2403	24.9483
737	839	2N2	0.271	2.4	0.92786	0.38454	23.6946	22.0321
840	890	N2	1.235	8.6	0.67563	0.07869	-6.2061	4.5089
891	947	**M2**	**7.964**	51.7	**0.83440**	0.01614	**-2.1748**	0.9253
948	987	L2	0.331	1.5	1.22570	0.81193	-42.1139	46.5190
988	1121	S2K2	3.562	24.0	0.80225	0.03344	10.0549	1.9517
1122	1214	M3	0.203	1.4	1.75008	1.26458	-2.1077	72.4234

- Standard deviation of weight unit: 8.563
- degree of freedom: 6543
- Adjusted meteorological or hydrological parameters:
- no. regr.coeff. stdv. parameter unit
- 1 6.91587 0.14803 mas /

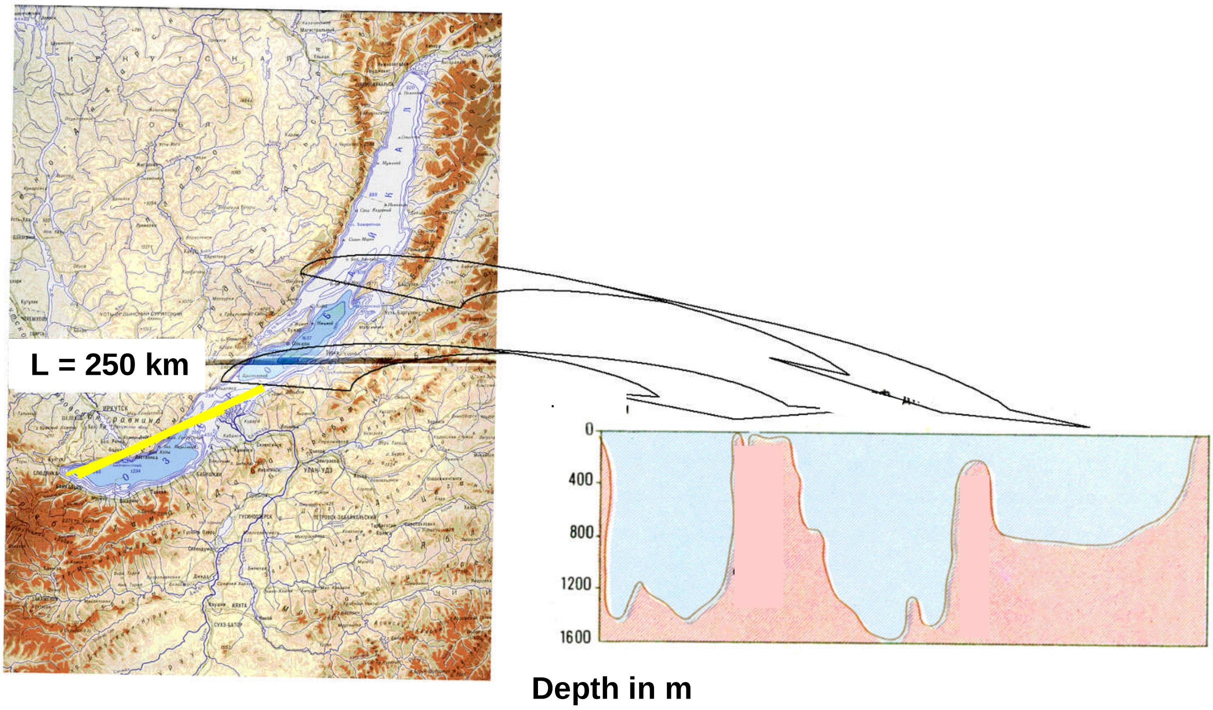


Figure 16. Baikal Lake: three hollows. Relief of Lake bottom from southern point to northern point [Baikal Atlas, 1993].

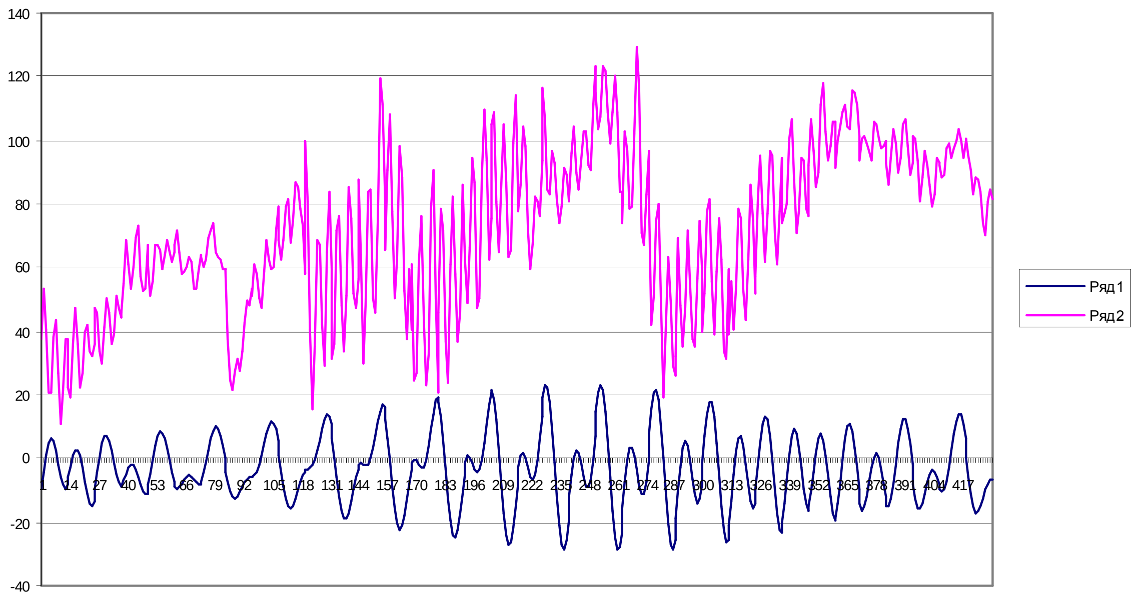
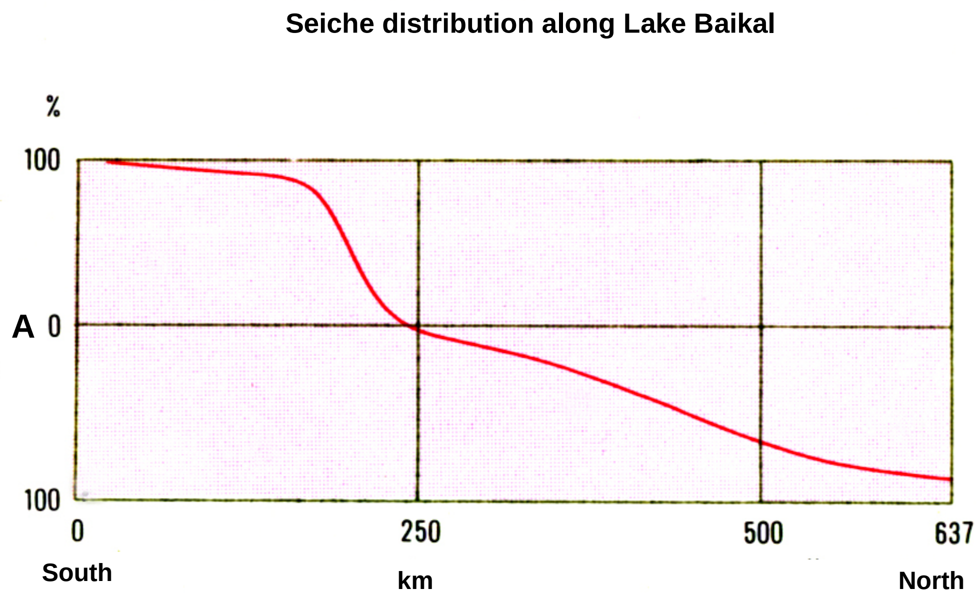


Figure 17. Baikal water level without tidal variation

– theoretical tidal curve (1, blue)

– seiche effect (2, red).

Seiches are generated at maximal tide. Double seiches amplitude reach 60 mm at Listvyanka point.



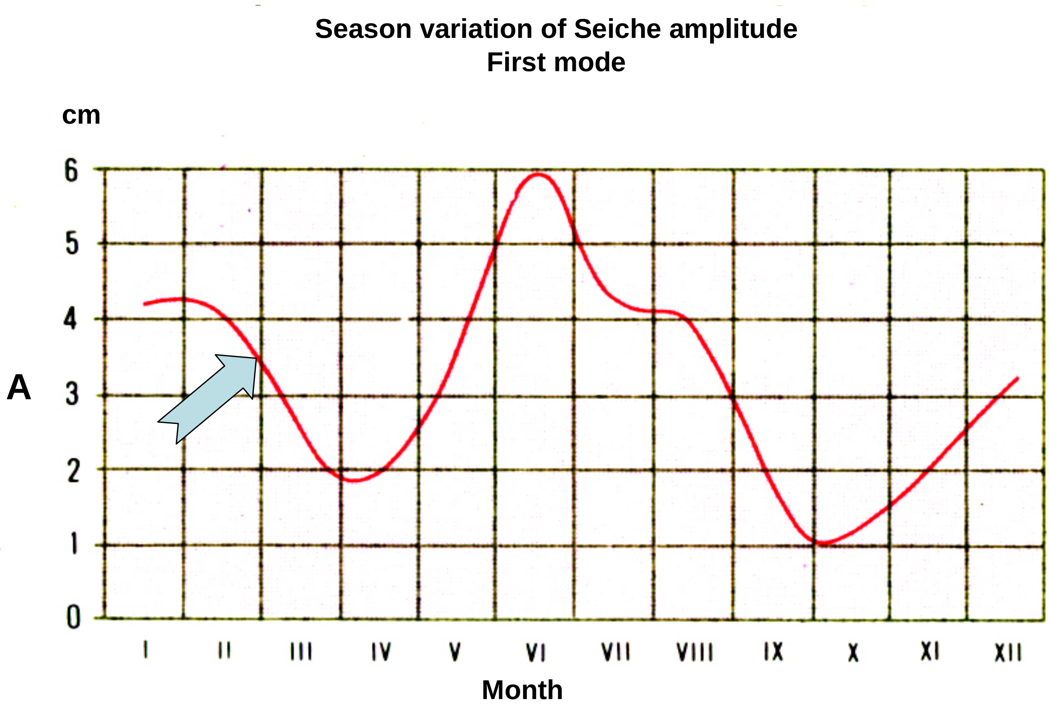


Figure 18. Seiche distribution along Lake Baikal (upper) and seasonal variations of Seiche amplitude in cm (lower) [Baikal Atlas, 1993].