Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 29(1), 2026, pp. 21-26

Phase Shift Between Water Level and X, Y, Z Components of Gravity Using the Example of Georgian Wells

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ABSTRACT

Various methods are used to detect and record earthquake precursors: measuring the water level and the rate of change, and studying the phase shift of the water level by comparing it with the Z-component of gravity (φZ). However, the X and Y-components of gravity remain obscured. Using the example of wells in Georgia, we will demonstrate the possible relationship between the phase shifts φX, φY and φZ, and, consequently, the informative value of their use.
Key words: *phase shift, water level, tidal X, Y, Z – components.*

Definition. Let φX denote the phase shift between the X-component of gravity (tidalX) and the water level (or its modification). Here tidalX is the North-South component of tidal gravity and tidalY is the East-West component. The phase shifts φY and φZ relate to tidalY and tidalZ, respectively. We will calculate the phase shift for principal semi-diurnal lunar constituent M_2=12.42 h., principal declinational diurnal constituent O_1=25.82 h. and principal solar semidiurnal constituent S_2=12.00 h. For wells in Georgia statements 1, 2 and 3 are *probably* true.
Statement 1. For M_2=12.42 h. the following relationships hold:

a) $\varphi Y - \varphi X \approx 90°$; b) $\varphi Z - \varphi Y \approx 90°$.

Statement 2. For O_1=25.82 h. the following relationships hold:

a) $\varphi X \approx \varphi Z$; b) $\varphi Z - \varphi Y \approx 90°$.

Statement 3. For S_2=12.00 h. the following relationships hold:

a) $\varphi Y - \varphi X \approx 90°$; b) $\varphi Z - \varphi Y \approx 90°$.

Below are facts supporting these statements.

Method for calculating phase shift

The Baytap08 program, suggested by D.C. Agnew, is often used to calculate the phase shift. Baytap08 is a modification of the Baytap-G program developed by M. Ishiguro, Y. Tamura, T. Sato, and M. Ooe [1]. This program, using well coordinates, calculates the Z-component of gravity and compares it with water level and atmospheric data. The results of its application to a study of Georgian wells are presented in [2]. The initial data had a sampling period of 1 hour.
Our approach. Gravity values (X, Y, Z components) for a selected well are pre-calculated. A version of the "solid"-program (Dennis Milbert [3]) is used to calculate them. Next, a MatLab-based program, suggested by ChatGPT, is used to compare the selected gravity component with the water level. The basic code is provided below.

Calculation Algorithm
We have water level values measured at 1-minute intervals, for example, from January 1 to December 1, 2025. Starting from the selected date:

1) Take all 1-minute water level values for a 30-day window. 2) Make comparisons, for example, with the X-component of gravity. 3) Assign the resulting value (phase shift in degrees) to our date. 4) Next, increase our selected date by 1 day and repeat the calculations. *Note:* The time interval (window) must be at least 30 days. To calculate the phase shift, we used a portion of the MatLab program provided by ChatGPT, modified to accommodate the input data. Here is a copy of the received text.

```
g_detrended = detrend(g); w_detrended = detrend(w); % Remove the trend (if any)
G = fft(g_detrended); W = fft(w_detrended); % Apply FFT
phase_g = angle(G); phase_w = angle(W); % Obtain phase spectra
N = length(t); % Frequencies (for plotting and analysis)
Fs = 1 / mean(diff(t)); % Sampling frequency (Hz)
f = (0: N-1) *(Fs/N); % Frequency vector
% Select the frequency of interest (for example, the main one - daily)
target_freq = 1 / (24*3600); % 1 time per day in Hz
 [~, idx] = min (abs (f - target_freq)); % Find the index of the nearest frequency
delta_phi = phase_w(idx) - phase_g(idx); % in radians % Calculate the phase shift
delta_phi = angle (exp (1i * delta_phi)); % Bring it into the range [-π, π]
delta_phi_deg = rad2deg(delta_phi); % Conversion to degrees
```

The program returns phase shift values in the range [-180°; +180°]. Therefore, if φ=187°, the program returns φ= -173°. Correction of the obtained data is necessary. When analyzing the tables below, it is useful to remember that if the function *f*(*x*) has a period of 360°, then, for example, *f*(*x*-270°) =*f*(*x*-270°+360°) =*f*(*x*+90°).

Information about wells

Kobuleti: coordinate 41.802°N, 41.772°E, depth 2000 m, screen 187-640 m.
Lagodekhi: coordinate 41.839°N, 46.282°E, depth 800 m, screen 255-367 m.
Gori: coordinate 41.485°N, 44.111°E, depth 1500 m, screen 960-1200 m.
Marneuli: coordinate 41.436°N, 44.755°E, depth 3505 m, screen 1235-1600 m.

Fig. 1 shows graphs of tidal X, Y, and Z gravity, as well as water level in kPa, for the Kobuleti well. The tidal graphs have different shapes. Calculating the phase shift between the water level and tidal_X for M2, then for tidal_Y and tidal_Z, yields different values. However, their values differ by 90° (see fig.2 and tables).

Below, *minus water* means (-1) **water* data.

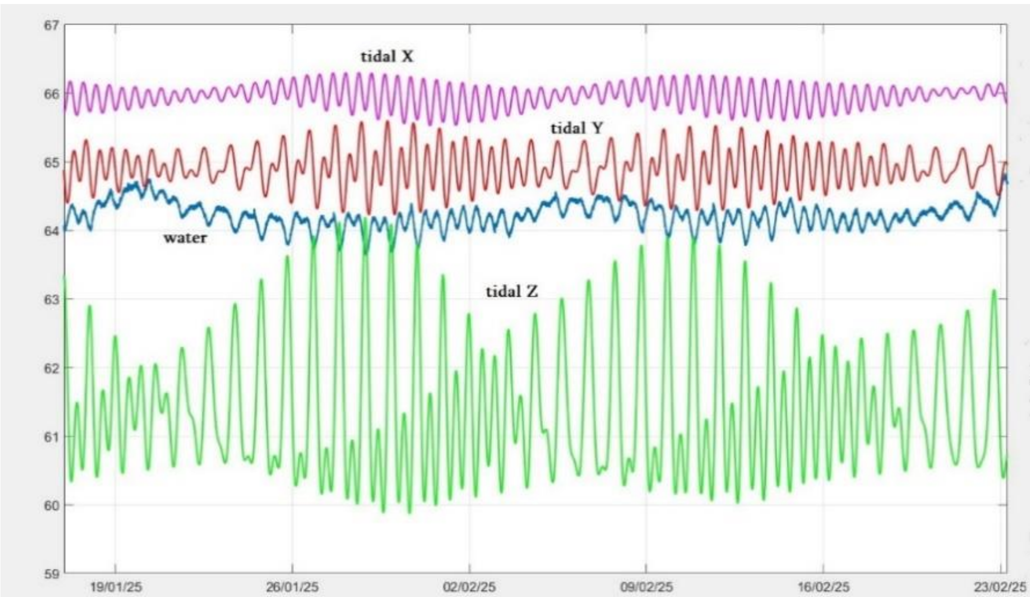

Fig.1. Tidal_X, tidal_Y, tidal_Z, Kobuleti water-k*atmos (blue line), in kPa, 2025

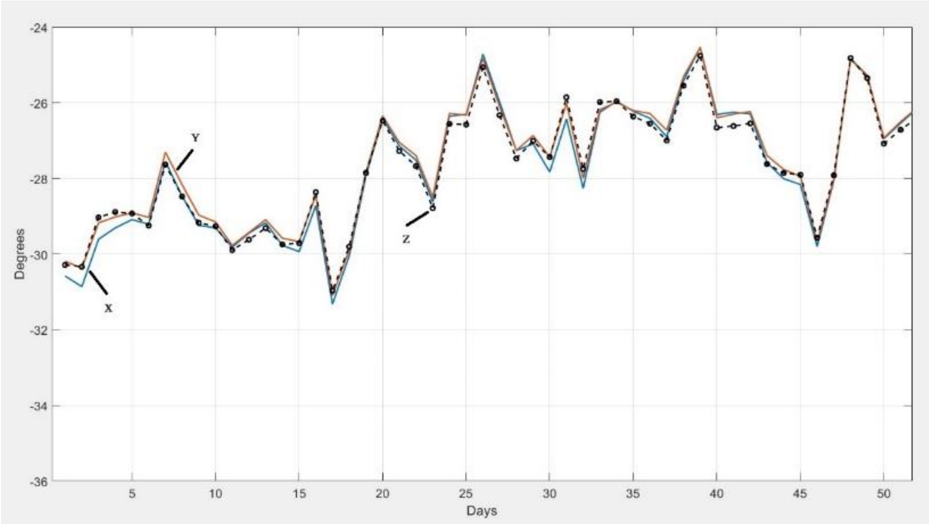

Fig.2. Kobuleti, phase shifts, M_2: φX (blue line), φY-90° (brown); φZ-180° (black, dashed line).
Use water, kPa, from 1 January 2025.

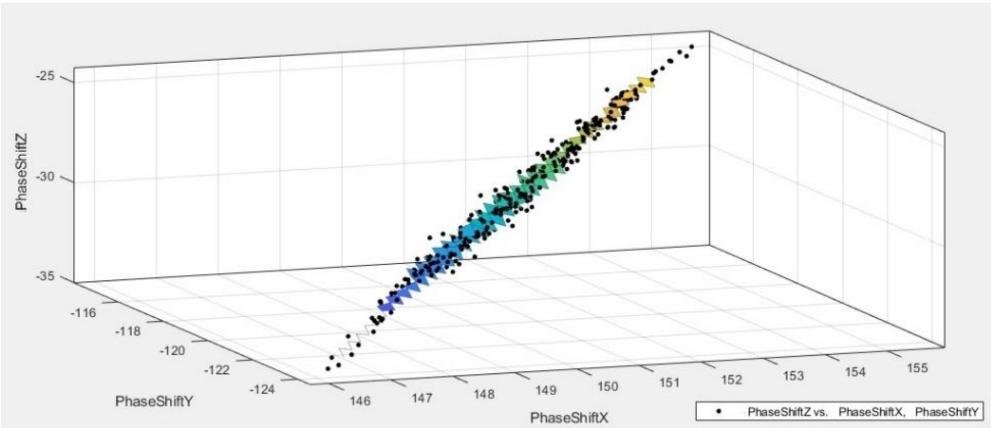

Fig.3. Kobuleti, phase shift X, Y, Z, degrees, M_2. Use minus water, kPa, 1 Jan - 1 Dec 2025

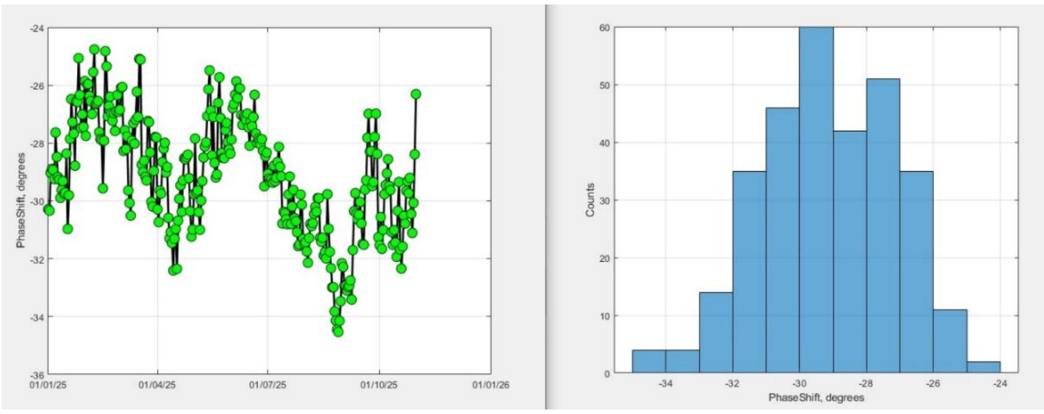

Fig.4. Kobuleti, phase shift Z for M_2, graph and histogram. Use minus water, kPa, 1 Jan - 1 Dec 2025

Information about M_2=12.42 hours

Formula: Y=p1*X+p2. Water data in kPa.

Table 1.1. Phase shifts for Kobuleti, 1 Jan - 1 Dec 2025, target: M_2=12.42 h.

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	1.014	90.41	1.014	-272.2
φX	φZ	1.014	180.4	1.014	-183.8
φY	φX	0.9783	-88.67	0.9783	267.4
φY	φZ	1.0120	89.04	1.0120	91.16
φZ	φX	0.9595	-173.8	0.9595	179.1
φZ	φY	0.9833	-87.24	0.9833	-90.25

Table 1.2. Phase shifts for Lagodekhi, 1 Jan - 20 Sep 2025, target: M_2=12.42 h.

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	1.015	90.94	1.015	-271.8
φX	φZ	1.033	181.8	1.033	-184.2
φY	φX	0.9827	-89.5	0.9827	267.4
φY	φZ	1.018	89.23	1.018	92.5
φZ	φX	0.9633	-175.4	0.9633	178
φZ	φY	0.9807	-87.46	0.9807	-90.94

Table 1.3. Phase shifts for Gori, 9 Mar - 1 Dec 2025, target: M_2=12.42 h.

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	1.007	89.9	1.007	91.24
φX	φZ	1.001	-180.4	1.011	181.5
φY	φX	0.9912	-89.09	0.9912	-90.68
φY	φZ	1.004	-270.6	1.004	90.02
φZ	φX	0.9865	178.0	0.9865	-179.6
φZ	φY	0.9956	269.5	0.9956	-89.69

Table 1.4. Phase shifts for Marneuli, 1 Jan - 1 Nov 2025, target: M_2=12.42 h.

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	1.007	90	1.007	-271.3
φX	φZ	1.017	179.8	1.017	-183.3
φY	φX	0.9886	-88.98	0.9886	269
φY	φZ	1.011	88.74	1.011	90.8
φZ	φX	0.9735	-175	0.9735	180.2
φZ	φY	0.9859	-87.25	0.9859	-89.78

Information about O_1=25.82 hours

Formula: Y=p1*X+p2. Water data in kPa

Table 2.1. Phase shifts for Kobuleti, 1 Jan - 1 Dec 2025, target: O_1=25.82 h.

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	0.9105	-74.36	0.9105	-90.46
φX	φZ	0.9075	15.93	0.9075	-0.7285
φY	φX	0.9829	91.28	0.9829	88.2
φY	φZ	0.9942	90.24	0.9942	89.2
φZ	φX	0.9867	2.409	0.9867	0.007052
φZ	φY	1.001	-90	1.001	-89.74

There is a good relation between φY и φZ. Relation φX => φY is bad, relation φY => φX is good. Relation φX => φZ is bad, relation φZ => φX is good.

Table 2.2. Phase shifts for Lagodekhi, 1 Jan - 20 Sept 2025, target: O_1=25.82 h.

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	0.7181	-49.88	0.7181	-100.6
φX	φZ	0.7041	41.89	0.7041	-11.4
φY	φX	0.9828	90.89	0.9828	87.8
φY	φZ	0.9754	91.03	0.9754	86.61
φZ	φX	0.996	0.809	0.996	0.092
φZ	φY	1.008	-90.9	1.008	-89.44

Relations φX => φY and φX => φZ are bad. Relations φZ => φX and φZ => φY are good.

Table 2.3. Phase shifts for Gori, 9 Mar - 1 Dec 2025, target: O_1=25.82 h

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	0.9319	-76.99	0.9319	-89.25
φX	φZ	0.9353	12.16	0.9353	0.5075
φY	φX	0.9394	95.05	0.9394	84.19
φY	φZ	1.00	89.75	1.00	89.79
φZ	φX	0.9385	10.92	0.9385	-0.143
φZ	φY	0.9956	-88.96	0.9956	-89.76

For *water* data the original values φ were pre-transformed for φX and φZ: if φ <0, then φ replaced by φ+360. For *minus water* φ-values are original. Relations φZ => φX and φZ => φY are good.

Table 2.4. Phase shifts for Marneuli, 1 Jan - 1 Nov 2025, target: O_1=25.82 h

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	0.8612	-65.11	0.8612	-90.1
φX	φZ	0.8504	26.57	0.8504	-0.3605
φY	φX	0.9545	93.94	0.9545	85.75
φY	φZ	0.9837	91.2	0.9837	88.27
φZ	φX	0.9635	6.65	0.9635	0.0936
φZ	φY	1.006	-90.77	1.006	-89.75

For *water* data original values φ transformed for φX и φZ: if φ <0, then φ replaced by φ+360. For *minus water* φ-values are original.

Formula: Y=p1*X+p2. Water data in kPa

Table 2.5. Phase shifts for Marneuli, 1 Jan - 1 Nov 2025, target: S_2=12.00 h

Axes X, degrees	Axes Y, degrees	Water		Minus water	
		p1	p2	p1	p2
φX	φY	0.9905	90.36	0.9905	88.64
φX	φZ	0.9944	-180	0.9944	179
φY	φX	1.009	-91.11	1.009	-89.57
φY	φZ	1.004	-270.7	1.004	89.98
φZ	φX	1.004	180.8	1.004	-180
φZ	φY	0.9958	269.6	0.9958	-89.62

Note. For periodic processes -270°=-270°+360°=+90°.

Conclusions

Analysis of the tables shows that for the selected well, the p1 coefficients for *water* and *minus water* are the same, while the p2 values fluctuate. The p2 coefficients are almost identical for Kobuleti, Lagodekhi and Marneuli, but differ by 360° from the coefficients for Gori. The p2 coefficients confirm the validity of the previously formulated statements 1, 2 and 3.

Note: Control calculations for Gori for the period 1 Jan – 1 Dec, 2021 showed that the p2 values for 2021 and 2025 are almost identical.

Acknowledgements. The scientific research has been funded and performed with financial support of the Shota Rustaveli National Science Foundation within the grant project **FR24-17839**.

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ფაზური წანაცვლება წყლის დონესა და გრავიტაციის X, Y, Z კომპონენტებს შორის საქართველოს ჭაბურღილების მაგალითზე

გ. კობზევი, თ. ჭელიძე, გ. მელიქაძე, თ. ჯიმშელაძე, თ. ქირია, ა. ჭანკვეტაძე, ზ. მაღრაძე, ნ. გოგუაძე

რეზიუმე

ნაშრომში განხილულია ფაზური წანაცვლებები ქობულეთის, ლაგოდეხის, გორისა და მარნეულის ჭაბურღილებში წყლის დონესა და გრავიტაციის X, Y და Z კომპონენტებს შორის. გრავიტაციული მიმოქცევის M_2, O_1 და S_2 კომპონენტებისათვის განსაზღვრულია ფაზური წანაცვლებების φX, φY და φZ ურთიერთკავშირი.

საკვანძო სიტყვები: ფაზური წანაცვლება, წყლის დონე, გრავიტაციის X, Y, Z კომპონენტები.

Фазовый сдвиг между уровнем воды и X,Y,Z-компонентами гравитации на примере скважин Грузии

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Т. Джимшеладзе, Т. Кирия, А. Чанкветадзе, З. Маградзе, Н. Гогуадзе

Резюме

Рассматриваются фазовые сдвиги между уровнем воды в скважинах Кобулети, Лагодехи, Гори, Марнеули и X,Y,Z-компонентами гравитации. Для составляющих гравитации M_2, O_1, S_2 определяется взаимная связь между фазовыми сдвигами $\varphi X, \varphi Y, \varphi Z$.

Ключевые слова: фазовый сдвиг, уровень воды, X,Y,Z-компоненты гравитации.