https://doi.org/10.59849/2219-6641.2026.1.28

MODEL ANALYSIS OF DAILY MAGNETIC FLUX DENSITY VARIATIONS AT THE ISMAYILLI GEOSTATION

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Abstract: In order to observe changes in the geomagnetic field strength (that is, magnetic induction - magnetic flux density) in 2025, 4 magnetometric variation stations (MVS) were operating in Azerbaijan – "Sheki", "Ismayilli", "Zagatala", "Lankaran" and "Gusar". The stations are equipped with American-made G-856 proton-type magnetometers and are equipped with internet connection facilities for initial analysis of the received data. The technical specifications of these stations are given using the example of the "Ismayilli" station. The daily average hourly and average daily magnetometric observation data from all MVS are recorded on the computer and transferred to the Magnetometry Department of the Seismological Service Center in Baku for analysis. The article shows the results of an experimental study of the daily variation of the magnetic flux density (magnetic induction) in the Imailla region of Azerbaijan. It was established that the magnitude of the magnetic induction decreases by 0.1% in the daytime between 12:00 and 16:00. This effect is related to the influence of the magnetic field created by the ionosphere, which increases during the day when the solar activity increases. A physical model of such an effect of solar activity is proposed, model calculations are performed.

Keywords: magnetic field, magnetic induction, solar activity, ionosphere, model

İSMAYILLI QEOSTANSİYADA ORTASUTKALIQ MAQNİT AXINININ SIXLIĞI VARİASİYALARIN MODEL ANALİZİ

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Xülasə

Azərbaycan ərazisində 2025-ci ildə geomaqnit sahə gərginliyinin (daha dəqiq desək, maqnit induksiyası - maqnit axınının sıxlığı) dəyişmələrini müşahidə etmək məqsədilə 5 maqnitometrik variasiya stansiyası (MVS) fəaliyyətdə olmuşdur - "Şəki", "İsmayıllı", "Zaqatala" , "Lənkəran" və "Qusar". Məntəqələrdə Amerika istehsalı olan G-856 markalı, proton tipli maqnitometrlər quraşdırılmış və alınan məlumatların ilkin təhlilini aparmaq üçün internet əlaqəsi vasitələri ilə təchiz olunmuşdur. Bu stansiyaların texniki göstəriciləri "İsmayıllı" stansiyasının misalında olaraq verilmişdir. Bütün MVS-dan gündəlik ortasaatlıq və ortasutkalıq maqnitometrik müşahidə məlumatları kompyuterə yazılır və təhlil olunması üçün Bakı şəhərinə Seysmoloji Xidmət Mərkəzinin Maqnitometriya şöbəsinə ötürülür. Bu məqalədə Azərbaycanın İsmayıllı rayonunda maqnit axınının sıxlığının (maqnit induksiyası) sutkalıq dəyişmələrinin eksperimental tədqiqatının nəticələri təqdim olunur. Məlum olub ki, gündüz saatlarında (12.00-16.00) maqnit induksiyası 0,1% **azalır. Bu təsir ionosferin yaratdığı maqnit sahəsinin təsiri ilə əlaqələndirilir və gündüz artan günəş aktivliyi ilə güclənir. Günəş aktivliyinin bu təsirinin fiziki modeli təklif edilir və model hesablamaları aparılır**.

Açar sözlər: maqnit sahəsi, maqnit induksiyası, günəş aktivliyi, ionosfer, model

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МОДЕЛЬНЫЙ АНАЛИЗ СУТОЧНЫХ ИЗМЕНЕНИЙ ПЛОТНОСТИ МАГНИТНОГО ПОТОКА НА ГЕОСТАЦИИ ИСМАИЛЛИ

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Аннотация

Для наблюдения за изменениями напряженности геомагнитного поля (точнее, магнитной индукции — плотности магнитного потока) в 2025 году в Азербайджане работали 5 станции магнитометрических вариаций (МВВ) — «Шеки», «Исмаилли», «Загатала», «Ланкаран» и «Гусар». Станции были оснащены протонными магнитометрами американского производства G-856 и средствами подключения к интернету для предварительного анализа полученных данных. Технические показатели этих станций приведены в таблице 1 на примере станции «Исмаилли». Среднесуточные почасовые и среднесуточные данные магнитометрических наблюдений со всех МВС записываются на компьютер и передаются в отдел магнитометрии Сейсмологического сервисного центра в Баку для анализа. В статье приведены результаты экспериментального исследования суточной вариации плотности магнитного потока (магнитной индукции) в районе Имаиллы Азербайджана. Было установлено, что в дневные часы 12.00÷16.00 величина магнитной индукции уменьшается на 0,1%. Этот эффект связан с воздействием магнитного поля, создаваемым ионосферой, который усиливается в дневное время при усилении Солнечной активности. Предложена физическая модель такого воздействия солнечной активности, выполнены модельные расчеты.

Ключевые слова: магнитное поле, магнитная индукция, солнечная активность, ионосфера, модель

Introduction

As a continuation of magnetometric observations conducted in previous years, in 2025, 4 magnetometric variation stations (MVS) were operational in Azerbaijan to observe changes in geomagnetic field strength (more precisely, magnetic induction - magnetic flux density) - "Sheki", "Ismayilli", "Zagatala", "Lankaran" and "Gusar".

All MVSs are equipped with modern magnetometric devices. American-made G-856 proton-type magnetometers are installed at the stations and are equipped with internet connection facilities for initial analysis of the received data. The technical indicators of these stations are given in Table 1, using the example of the “Ismayilli” station. Daily average hourly and average daily magnetometric observation data from all MVSs are recorded on a computer and transmitted to the Magnetometry Department of the Seismological Service Center in Baku for analysis. Here, the method described in the article [Bayramov et.al., 2021] was used.

Table 1.

Technical indicators of the stations, using the example of the “Ismayilli” station.

Observation stations	Devices type	Observed parameters,Earth's magnetic induction, (nTl)	Measurement limit, (nTl)	Measurement error, (nTl)	Operating temperature range, ^{o}C
İsmayıllı	G-856	T	20000÷100000	±0,1	-20^{o}C÷+50

Analysis of the average hourly Sq~f(t) variations during the lunar-solar attraction during the day shows that they pass with the same flow at all observation stations. While at night (from 01 to 06 and from 20 to 24), the voltage on the Sq~f(t) graph is approximately at the background level, a decrease of the geomagnetic field voltage by 30÷40 nT is observed from 1000 to 1600, and then a gradual increase until 1800 and a return to the previous level is observed (Fig. 1).

Thus, it can be said that the surface electromagnetic waves are distributed uniformly between the points in a circle of 10 longitudes and 10 latitudes. Analysis of the Sq variations proves that the magnetic field in both polygons is the same on days when it is constant.

The oscillations of the average diurnal variations T~f(t), are presented in a large spectrum. As a result of the influence of infiltration processes in the Earth's crust, low-frequency harmonic fluctuations with an amplitude of 5.0 ±0.5 nT, which are most likely directly related to magnetic induction, are clearly traced. The degree of this "obstacle" is at the level of the accepted errors of seismomagnetic observations. Low-frequency harmonics complicate the T voltage field with high-frequency impulsive vibrations. Such magnetic storms are separated from the solar plasma and are observed on the Earth's surface as a strong impact wave.

Geomagnetic variations.

Observed anomalous magnetic changes sometimes last up to 2-3 days. The amplitude of large anomalous magnetic changes can reach 30-50 nT. The high-frequency signal has a sharp form from several hours to 1-2 days. Changes in this intensity are "leaping" and spread simultaneously (synchronously) across all stations, which is related to the electromagnetic processes occurring in the ionosphere. Such interference signals are removed by cleaning with the linear transformation method during comparative analysis. A comparative analysis method was carried out in order to overcome the ionospheric "barrier" factors and electromagnetic induction from the observed T voltage field variations. As a result, $\Delta T(t) = T_m(t) - T_o(t)$, in which $T_m(t)$-t was taken as the field voltage value observed at the base station and $T_o(t)$ - t at all stations.

The study of the anomalous changes in the stress in the geomagnetic field during the effect of the stress caused by the excess elastic waves on the rocks in the zones near the epicenters of the earthquake shows that the seismomagnetic effect changes independently of the main directions of the stress in the centers of the earthquake [Rzaev, 2013].

The local variation of the geomagnetic field voltage in the seismogenic zones is calculated using the following formula [Rzaev, Isaeva,2006]:

$$\Delta H= \Delta ae(\sigma)\, H + I_r\,(\sigma)$$

Here, ΔH is a local variation of the geomagnetic field voltage under overvoltage conditions (seismomagnetic effect).

Calculations have shown that for the Sheki-Shamakhi polygon, theoretically, the diaposon of the seismomagnetic effect can be expected to change by 15-25 nT. The results of the studies of seismomagnetic researchers of previous years show that when the compressive stress in the source is dominant, the seismomagnetic effect (SME) is formed due to the positive increase of the geomagnetic field [Rzaev, 2005].

When tensile deformation occurs in the furnace, SME has a negative sign and is observed with decreases. The observed increase or decrease can be up to 15–30 nT, which corresponds to the theoretically calculated values of SME.

The analysis of magnetic variation curves ΔT~f(t) allowed the detection of a number of events related to the seismomagnetic effect before the earthquake (Ml≥4.0). Seismomagnetic effects reflect the mechanism of the geodynamic state of the seismic stress centers located in the blocks in the Earth's crust [Rzaev, 2006, 2013].

It is known to researchers that geomagnetic anomalous changes are observed due to strong earthquakes in seismically active areas. The studies carried out by the magnetometric method allow specifying the boundaries of geological structures [Rzaev, 2006; Rzaev, Etirmishli and others, 2013].

Accumulation of stress-strain energy at different depths of the earth is related to internal and cosmogenic factors. The mechanical, physico-chemical and other properties of the environment change with characteristic indications in the Middle and Lower Kura depressions, where anomalous stress-strain energy accumulates, in the earthquake foci that occur in the northern and southern foothills of the Greater Caucasus, Kuratrafi-Talish. The effect of such active processes on the earth's surface is studied in the seismoactive regions of the world as the anomalous changes of geophysical fields: gravity, electricity, magnetism and geochemistry, warning factors of earthquakes.In Figure 1, as an example, the mean diurnal variations of Sq on 25.02.2025 at the Ismayilli station are presented.

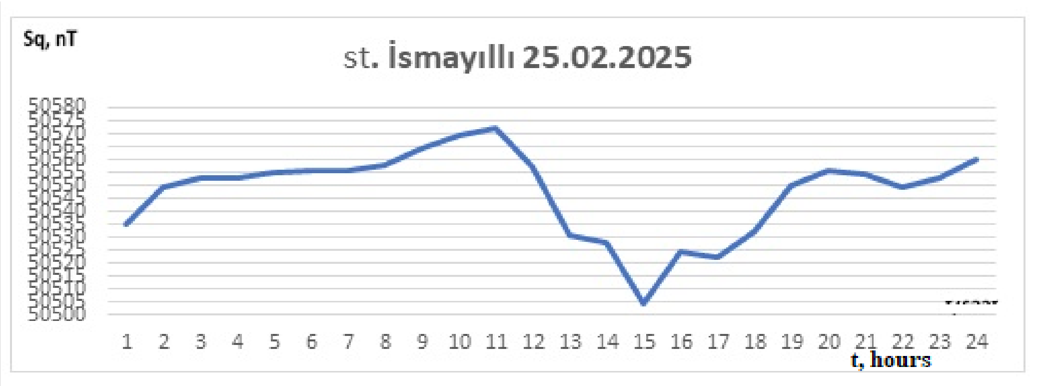

Fig. 1. Mid-day variations at Ismayilli station on 25.02.2025.

It can be seen from Figure 1 that during daytime hours, from approximately 11:00 to 20:00, the intensity of the Earth's magnetic field (magnetic induction) decreases by ~ 30 nT, i.e. ~ 0.1%, from the average value. The reason for this decrease is related to the ionosphere and solar activity. The atmosphere conducts electricity, and the currents in it create a magnetic field that adds up to the Earth's. Below we consider a model of such daily behavior of the magnetic field.

A model of mean diurnal geomagnetic variations.

At noon, the strength of the Earth's geomagnetic field drops for the following reasons. Solar radiation strongly ionizes the ionosphere. During the day, especially at noon, solar radiation is maximum, the concentration of ions is higher and the ionosphere becomes a better conductor of electrical charges. Currents arise in the ionosphere (Sq-currents - Solar quiet currents). These currents form ring systems around the Earth and create their own magnetic field. The magnetic field of Sq-currents partially compensates (weakens) the main dipole field of the Earth. Therefore, the measured magnetic field strength at the surface decreases slightly during the day. The maximum attenuation is around local noon, when solar forcing and ionospheric currents are strongest.

Typically, the magnitude of daily variations is tens of nT, which is less than 0.05–0.1% of the total field (≈50,000 nT). This is what we see in Fig. 1. Thus, at noon, the magnetic field strength drops because the ionosphere, enhanced by solar radiation, generates currents that create a magnetic field opposite to the earth's, which leads to a small, 0.1% weakening of the resulting field.

Let us imagine ionospheric Sq-currents as an equivalent circular ring of radius (a) and height (h). The equivalent total ring current I is estimated as $I = K \cdot 2\pi a$, where $K = \Sigma E$ is the surface current density (Pedersen conductance) [Evans et.al., 1977]. The magnetic field on the axis from the ring (at a point under the ring, on the surface) is calculated using the following formula

$$B_{ring}(x) = \frac{\mu_0 I a^2}{2(a^2 + x^2)^{3/2}}$$

Here: $x = h$ – distance from the plane of the ring to the observer.

The resulting field, taking into account that the field from Sq is usually directed opposite to the vertical component of the dipole at noon, is equal to

$$B_{total}(t) = B_0 - B_{ring}(t)$$

If, for example, we take a = 2000 km, h = 110 km, the typical daytime Pedersen conductivity is [Mishin et.al., 2011] Σ = 5 S and E = 1 mV/m, then $K = 5 \cdot 10^{-3}$ A/m and the equivalent current is

$$I_{max} \approx 6{,}283 \cdot 10^4 \text{ A} \approx 63 \text{ kA}$$

We take the dipole field B_0 = 50000 nTl. Maximum ring field amplitude $B_{sq,max} \approx 19.65$ nTl. At noon, the resulting field Btotal ≈ 49980 nT, that is, a drop ~ 19.65 nTl compared to the dipole. The daily current shape has the form

$$I(t) = I_{max} max\left[sin\left(\frac{\pi t}{24}\right), 0\right],$$

that is, at night 0 and maximum at 12.00.

Modeling of daily Sq variations of the Earth's magnetic field.

Statement of the problem. Let us assume that from experimental measurements it has become known that the average induction of the Earth's magnetic field during the day is B_{avr} = 50555 nT. At noon at 15.00 the strength of the Earth's magnetic field was 50505 nT. Let's build a mathematical model of the influence of solar activity on the state of the ionosphere and its influence on a given daily variation of the Earth's magnetic field.

To model daily Sq variations of the Earth's magnetic field (Solar quiet) under the influence of solar activity, the concept of an ionospheric dynamo is used [Kopp et al., 2015]. The daily variation of the magnetic field ΔB(t) under quiet conditions is explained by the emergence of electric currents in the ionosphere (layers E and F) under the influence of solar ultraviolet radiation.

Main assumptions and parameters of the model:

1. Ionization and conductivity: Solar activity (F10.7 index or Wolf number R) determines the degree of ionization of the atmosphere. The conductivity of the ionosphere Σ is directly proportional to the flux of solar radiation.

2. Dynamo effect: The movement of neutral gas (tides) in the Earth's magnetic field generates electromotive force (EMF). The current density is equal to

$$j = \Sigma(E + v \times B_0).$$

3. Magnetic effect: These currents create an additional magnetic field ΔB, which appears on the Earth's surface as a diurnal cycle.

To simplify calculations, a harmonic model (Fourier approximation) is used, where the amplitude of variations depends on solar activity:

$$B(t) = B_{avr} + A(S) \cdot cos\left(\frac{2\pi(t - t_{peak})}{24}\right),$$

where B_{avr}=50555 nT is the average magnetic field induction, $A(S)$ is the amplitude depending on the level of solar activity S, t_{peak} is the time of maximum/minimum (around noon).

Calculation algorithm.

1. 1. Definition of parameters: Entering the average value B_{avr}=50555 nT and the local value at 15.00 (50505 nT).
2. Deviation calculation: ΔB = 50505 – 50555 = - 50 nT.
3. Calibration of the model: Selection of the amplitude coefficient so that at t = 15.00 the value corresponds to the specified.
4. Generation of daily cycle: Calculation of values for each hour (0 – 23).
5. Visualization: Plotting a graph of tension versus time.

Below is a Python program for modeling and plotting (Fig. 2) this variation.

```
import numpy as np
import matplotlib.pyplot as plt
# Input data
B_avg = 50555  # Daily average, nT
B_15 = 50505   # value in 15:00, nT
t_obs = 15.0   # Observation time
```

```
# 1. Calculation of the amplitude of daily variation (A)
# Model: B(t) = B_avg + A * cos(2 * pi * (t - 12) / 24)
# From the condition at 15:00: B_15 = B_avg + A * cos(2 * pi * 3 / 24)
delta_B = B_15 - B_avg
cos_factor = np.cos(2 * np.pi * (t_obs - 12) / 24)
A = delta_B / cos_factor
print(f" Calculated amplitude of variation: {A:.2f} нT")
# 2. Timeline generation and field calculation
hours = np.linspace(0, 24, 100)
magnetic_field = B_avg + A * np.cos(2 * np.pi * (hours - 12) / 24)
# 3. Plotting a graph
plt.plot(hours, magnetic_field, label=" Modeled field ")
plt.axhline(B_avg, color='r', linestyle='--', label=" Average value")
plt.scatter(t_obs, B_15, color='black', label="Data at 15:00")
plt.title("Mathematical model of daily variation (Sq)")
plt.xlabel("Time, h")
plt.ylabel("B, nT")
plt.legend()
plt.grid(True)
plt.show()
```

A decrease of 50 nT at 15:00 indicates active processes in the daytime ionosphere (increased conductivity due to the Sun), which create a counter-directional field at a given observation point. With increasing solar activity, the amplitude A will increase, as the concentration of electrons in the ionosphere increases, which enhances the dynamo effect currents [Givishvili & Leshchenko, 2009].

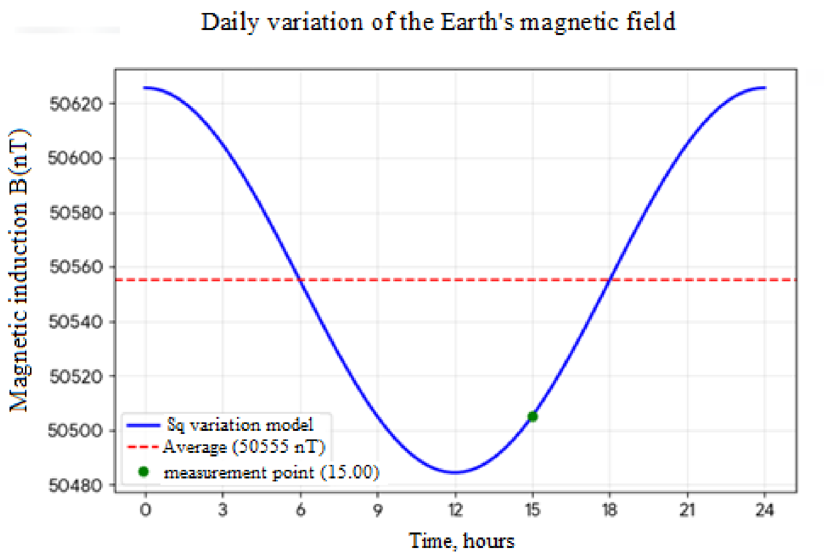

Fig. 2. The result of modeling the daily variation of the Earth's magnetic field.

Conclusion

Thus, the results of experimental measurements of daily variations in magnetic flux density (magnetic induction) in the Imailly region of Azerbaijan have been studied. It was found that in the daytime hours of 12.00–16.00 the value of magnetic induction decreases by 0.1%. This effect is associated with the influence of the magnetic field created by the ionosphere, which intensifies during the daytime with increased solar activity. A physical model of such effects of solar activity has been proposed, and model calculations have been performed.

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