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Increasing the accuracy of absolute measurements at the Argentine Islands geomagnetic observatory of the Ukrainian Antarctic Akademik Vernadsky station

Abstract. In recent years, the INTERMAGNET geomagnetic observatory Argentine Islands of Ukrainian Antarctic Akademik Vernadsky station, located at Galindez Island, has been modernized. New devices were installed at the observatory: reference three-component fluxgate magnetometer LEMI-025, one-component Mag-01H Fluxgate Declinometer/Inclinometer with non-magnetic Wild T1 Theodolite (DI-magnetometer), and scalar Overhauser magnetometers GSM-19 and GSM-90. These devices have a high resolution and can carry out measurements with greater accuracy. Also, new methods of absolute observations and variation processing were introduced. In 2022, a new DI-magnetometer was installed; it practically did not change the baseline values of the variometer LEMI-025 compared to previous years, which indicates the reliability of the results, but made observations much more convenient. We present the results of processing absolute observations, carried out by different methods. Different techniques of calculating these observations are described, and certain shortcomings or inaccuracies in their application are noted. Recommendations to eliminate the identified shortcomings are proposed. The results of processing of absolute observations by different techniques are compared and the reason for the inconsistency of certain values is found. A new method of calculation of absolute observations is proposed, which was used at the observatory, which showed quite good results. In the new methodology, the calculation of errors of the DI-magnetometer, namely: the zero offset of the magnetic sensor, the azimuth collimation error δ and the elevation collimation error ε of its sensitivity axis relative to the axes of theodolite, is initiated. Analysis of these errors allows identifying and sometimes correcting the errors in absolute measurements. The installation of new devices and the application of new calculation methods made it possible to ensure better data quality and convenience of measurements at the station, to automate the data processing, preparation, and minimizing the influence of the human factor.

Keywords: absolute observations, declination, geomagnetic observatory, inclination

1 Introduction

The world network of magnetic observatories INTERMAGNET (International Real-time Magnetic Observatory Network) was created in 1991. This network

united observatories with digital registration, which agreed to send diurnal data to the geomagnetic information centers (nodes) (GIN) within 72 hours. Also, the procedure of implementing definite requirements for the measurement and data processing of the geo-

magnetic field was agreed upon. In the beginning, the network united 47 of such observatories. The GINs were created in Canada, UK, Japan and France. The observatories sent their data to these GINs, and the centers checked them for compliance with the accepted format and published them on CD-ROMs. Every member of INTERMAGNET has the right to use the data of all members of this network. Today the INTERMAGNET network unites more than 110 world observatories, including the Ukrainian Antarctic Akademik Vernadsky station, successor to the British Faraday Station since 1996. The geomagnetic observatory was organized in 1955 (according to the IAGA catalogue, its code is AIA, Argentine Island Archipelago) when regular registration of the Earth's magnetic field began (Cotton & Simmons, 1986). Since 2004, the AIA observatory has joined the INTERMAGNET network (Melnyk & Bakhmutov, 2007/2008; Sumaruk et al., 2011). It regularly sends measurement records to the GINs according to schedule. The AIA observatory has the longest series of geomagnetic observations in Antarctica, which allows studying geomagnetic variations over different periods, including secular variations (Sumaruk, Yu. P., & Sumaruk, T. P., 2016). In addition, the AIA observatory is the basic one in the Antarctic Peninsula region for the network.

The INTERMAGNET membership requires meeting certain standards for observing and processing geomagnetic field data (St-Louis, 2020). Therefore, one of the most important tasks of the AIA observatory is to obtain high-quality measurements by the followed procedure.

A set of improvements in the observing technique, instrumentation, and processing method was initiated to increase the accuracy of measurements in the difficult conditions of Antarctica. For this, the State Institution National Antarctic Scientific Center (SI NASC) of the Ministry of Education and Science of Ukraine acquired novel higher-quality devices, and modern data processing methods were implemented. This process started in 1998 and continues today (Marusenkov et al., 2019).

The purpose of this paper is the description of recent improvements at the AIA observatory and the discussion different processing algorithms to select the most suit-

able to minimize possible instrumentation and observation procedure errors. First, the newly installed advanced instrumentation is considered. Then, the data format, different processing methods, and the results of their comparison for error minimization. Finally, the conclusion summarizes the results and gives an efficiency estimation of the newly introduced processing method.

2 Equipment, data, and methods

2.1 Equipment for magnetic field measurements

Today, the AIA observatory is equipped with two flux-gate magnetometers made in Ukraine. Since 2003, the magnetometer LEMI-008 has been working quite successfully, providing one-minute magnetic field measurement data to the INTERMAGNET network. In 2020, measurements were started using the novel magnetometer LEMI-025 which obtains high-precision one-second data in the IAGA-2002 format (St-Louis, 2020). This improvement revealed problems in the operation of the magnetometers, particularly in the absolute measurements' calculation accuracy. To eliminate them, new equipment was installed, and a more advanced data processing system was implemented. The State Institution National Antarctic Scientific Center has acquired a set of new equipment for the modernization of the geomagnetic observatory consisting of the Wild T1 non-magnetic theodolite with Mag-01H one-component magnetometer, GSM-19 scalar magnetometer/gradiometer and GSM-90 scalar magnetometer.

The Mag-01H magnetometer, installed on a non-magnetic theodolite Wild T1 (Fig. 1), allowed the angular measurements of the terrestrial magnetic field vector B – declination D and inclination I . The angular resolution of the theodolite Wild T1 is 6 arc seconds, so an experienced observer can make measurements with an error within 2 arc seconds.

Magnetometer Mag-01H has a range of magnetic field measurements of ± 0.2 mT, drift in zero fields not more than ± 1 nT, and a maximum resolution of 0.1 nT. The Mag-01H electronics unit has an internal battery, which allows it to carry out the monitoring autonomously.

The Overhauser GSM-19 magnetometer allows directly sensing the Earth's magnetic field F in the range 15,000 to 120,000 nT (Fig. 2) with a resolution of 0.01 nT and absolute accuracy of ± 0.1 nT. It executes measurements in a rapid cycle, which in the standard mode is 3 s, but can be decreased up to 0.2 s, and a wide temperature range – from -40 °C to $+50$ °C. All these features make it convenient in the conditions of the Antarctic geomagnetic observatory.

Scalar magnetometer GSM-90 (Fig. 3) permanently records the magnetic field scalar total intensity F in geomagnetic observatories. Its operation principle is the same as GSM-19 and is based on the Overhauser effect.

For baselines of variometer records estimation, the absolute measurements of the elements of the Earth's magnetic field vector are regularly carried out at the geomagnetic observatory (Jankowski & Sucksdorff, 1996), and its goal is to provide baseline values for magnetic variations' calculation.

Absolute measurements at the AIA observatory are regularly made during the whole year. Similarly to the observatories in the USA (Worthington & Matzka, 2017), they are carried out both by the “zero” method (A) and by the “residual” method (B). The obtained data are processed to determine the exact values of the declination D and inclination I angles. Given the accurate data of these angles and the modulus of the magnetic field vector F , the values of the components of the Earth's magnetic field are calculated and compared with the measured values of the three-component magnetometer. In this way, the real errors of the magnetometer measurements – the baselines – are determined. The exact method of processing these data determines the accuracy of the obtained result. The methods of the calculations used at the AIA station are discussed in the next subsection, 2.2.

2.2 Data

We use the data collected during absolute measurements at the AIA geomagnetic observatory with the help of the following available instrumentation: two theodolite-mounted one-component magnetometers Wild T1 and Theo-020-B to record DI ; proton mag-



Figure 1. Non-magnetic theodolite Wild T1 with fluxgate MagA and magnetometer Mag-01H



Figure 2. Scalar magnetometer GSM-19



Figure 3. Scalar magnetometer GSM-90

netometer PMP-8 and Overhauser magnetometer POS-1 for absolute field measurements, and fluxgate magnetometer LEMI-025 for the components of geomagnetic field data.

The input data set for the session of absolute measurements by the zero method (method A) is presented in Table 1. The data taken at different stages of absolute measurements are shown in Table 1 with dif-

Table 1. Input data for calculating the magnetic field’s absolute elements and the variometer’s baseline values (the data taken at different stages of absolute measurements are shown in Table 1 with different colours)

Time stamps	LEMI-025	POS-1	PMP-8	DI-flux	
–	*	*	–	A1	sensor above telescope
–	*	*	–	A2	sensor under telescope
t1	X1, Y1, Z1	F1	–	D1	West-up
t2	X2, Y2, Z2	F2	–	D2	East-up
t3	X3, Y3, Z3	F3	–	D3	West-down
t4	X4, Y4, Z4	F4	–	D4	East-down
t5	X5, Y5, Z5	F5	T1	–	
t6	X6, Y6, Z6	F6	T2	–	
t7	X7, Y7, Z7	F7	T3	–	
t8	X8, Y8, Z8	F8	T4	–	
t9	X9, Y9, Z9	F9	T5	–	
t10	X10, Y10, Z10	F10	–	I1	North-down
t11	X11, Y11, Z11	F11	–	I2	South-down
t12	X12, Y12, Z12	F12	–	I3	North-down
t13	X13, Y13, Z13	F13	–	I4	South-up
t14	X14, Y14, Z14	F14	T6	–	
t15	X15, Y15, Z15	F15	T7	–	
t16	X16, Y16, Z16	F16	T8	–	
t17	X17, Y17, Z17	F17	T9	–	
t18	X18, Y18, Z18	F18	T10	–	
–	*	*	–	A3	sensor above telescope
–	*	*	–	A4	sensor under telescope

Notes: “*” data are registered but not used when calculating; “–” data are not registered.

ferent colours. With DI-magnetometer, the operator carries out the measurements of the reference azimuth mark horizontal angles (A1-A4), magnetic declination (D1-D4), and magnetic inclination (I1-I4). The data of the DI-magnetometer and proton magnetometer PMP-8 are recorded into measurement protocol with exact fixation of time by the operator. Data from LEMI-025 and POS-1 are taken from a text file in IAGA-2002 format.

2.3 Data processing methods

Three different methodologies were used to process the data by method A. According to the former methodology, which is still used at the station, the operator transfers the data of LEMI-025 and POS-1 from the IAGA-2002 file to the protocol form and the Excel file, where the calculations are executed. With the new methodology, the calculations are carried out in another Excel file, where data are automatically copied from the Excel file of the former methodology and the IAGA-2002 file with the help of a special program. Also, from the beginning of March 2022, the data of absolute measurements by method A were processed by the ABS.exe program, mainly used in geomagnetic observatories in Poland and Ukraine. The program was adapted for processing data from places with negative values of magnetic inclination (South Hemisphere). In calculating with the ABS.exe program, theodolite data A1-A4, D1-D4, I1-I4, variometer data X1-X4, Y1-Y4, X10-X13, Y10-Y13, Z10-Z13, and proton magnetometer data (PMP-8 or POS-1) at intervals t14–t16 were used.

Besides these data, for the processing of absolute measurements, the following additional known parameters are used: the reference mark azimuth A_z , compensation values X_c , Y_c , and Z_c of the LEMI-025 variometer (only with the new method), and gradients of the magnetic field total intensity between the theodolite pillar and the pillars of the sensors PMP-8 (P1), POS-1 (P2) and LEMI-025 (P3). Until 2020, the following gradient values were used in calculating the baseline values: $P1 = +4.5$ nT, $P2 = -5$ nT. Therefore, it was considered that the difference between the PMP-8 and POS-1 sensors pillars was $P2 - P1 = -9.5$ nT.

After installing a new instrumental set based on the LEMI-025 variometer in 2019 and eliminating magnetic impurities in the variation pavilion, the real difference between the readings of PMP-8 and POS-1 magnetometers was -8.8 nT. Thus, until April 15, 2021, the baseline values were calculated using the following gradient values: $P1 = +4.5$ nT, $P2 = -4.3$ nT.

In 2021, after the experiments with the movements of the POS-1 sensor, its readings changed, and the value $P2 = -4.75$ nT was used. The PMP-8 data for almost the whole of 2020 and a part of 2021 were unstable. From May 2021, after resuming its normal operation, the difference in PMP-8 and POS-1 readings was -8.1 nT. In the result, the value $P1 = 3.35$ nT was used.

On March 23, 2022, the old equipment was removed from the room where the sensor of the POS-1 magnetometer was installed. It caused a change in its records by $+9.1$ nT. Thus, since March 23, the value of $P2 = -13.85$ nT has been used. In 2019, before the installation of the LEMI-025 sensor, the gradient between the pillars of the theodolite and LEMI-025 was checked, which was $P3 = 13.4$ nT. It should be noted that the measurement of the gradients between the pillars requires a special study, as the previous measurements detected a considerable heterogeneity of the field on the surface of the PMP-8 and theodolite pillars as well as around the POS-1 and LEMI-008 pillars (see Leonov & Otruba, 2021). However, it goes beyond the tasks of this paper.

According to the former methodology, the processing of the results of absolute measurements uses the calculation of the following parameters: inclination and declination (I_{abs} , D_{abs}) of the magnetic field vector in the selected frame (axis x to the North, axis y to the East, axis z to the bottom), absolute values of the horizontal (H_{abs}) and vertical (Z_{abs}) vector components, baseline values of variometer components X_{base} , Y_{base} , Z_{base} , and additional baseline values H_{base} , D_{base} . According to the new methodology, in addition to the parameters mentioned above, the DI-magnetometer instrumental errors are calculated: magnetic sensor zero drift $SO(D)$, $SO(I)$, the angles δ , $\varepsilon(D)$, $\varepsilon(I)$, which reflect imperfect parallelism of the optical and the magnetic axes of the telescope and the fluxgate sensor respectively, and the parameter ΔI ,

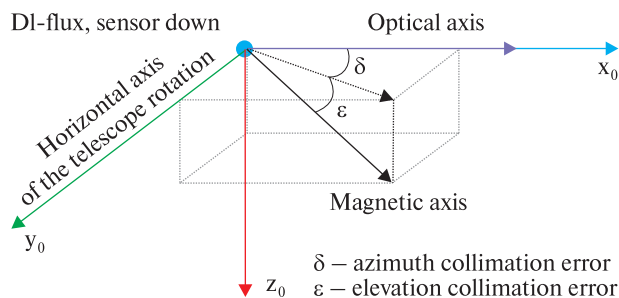


Figure 4. The difference between the optical axis of the telescope and the sensor magnetic axis

which characterizes the discrepancy in measurements of magnetic inclination. Also, the difference ΔF_{pillar} of both absolute magnetometers' pillars and the total field difference ΔF between readings of the LEMI-025 variometer and the POS-1 absolute magnetometer are evaluated. The last parameter is important for analysing the variometer measurements' stability and is invariant to its sensor orientation.

Zero drift of the magnetic sensor is calculated based on the data on both the magnetic declination $-SO(D)$ and the magnetic inclination $-SO(I)$. The difference between the telescope's optical axis and the magnetic sensor's sensitivity axis (magnetic axis) is given by two angles, as shown in Figure 4.

The azimuth collimation error δ (in the x_0y_0 plane) is estimated based on measurements of the magnetic declination. The elevation collimation error ε (the deflection from the plane x_0y_0) and the zero drift are estimated using the measurements of magnetic declination ($\varepsilon(D)$) and inclination ($\varepsilon(I)$).

At present, when calculating $\varepsilon(D)$, the absolute value of the magnetic inclination at the interval $T10-T13$ is used, although it should be used more correctly the value at the interval $T1-T4$. However, it does not necessarily affect the accuracy of ε estimation.

To calculate the magnetic inclination, it is enough to conduct measurements at two positions: North-up, South-up or North-down, and South-down (Rasson, 2005). Having measurements of angles at all four positions, inconsistency of magnetic inclination estimations can be determined. Significant variation of this parameter from zero can indicate the magnetic impurity of the theodolite or the pillar (Rasson, 2005).

Table 2. Equations for magnetic field calculations

Parameter	Old technique A	New technique A
F_{abs}	$F_{old} = \frac{1}{10} (\sum_{i=5}^9 F_i + \sum_{i=14}^{18} F_i) + P2$	$F_{new} = \frac{1}{4} \sum_{i=10}^{13} F_i + P2$
H_{abs}	$H_{old} = F_{old} \cdot \cos(I_{abs})$	$H_{new} = F_{new} \cdot \cos(I_{abs})$
Z_{abs}	$Z_{old} = F_{old} \cdot \sin(I_{abs})$	$Z_{new} = F_{new} \cdot \sin(I_{abs})$
D_{abs}		$\frac{1}{4} \sum_{i=1}^4 (D_i - A_i) - \frac{\pi}{2} + A_z$
I_{abs}		$[I_1 + I_2 - I_3 - I_4 - 2\pi] / 4$
D_{base}	$D_{abs} - \arctan\left(\frac{\frac{1}{4} \sum_{i=1}^4 Y_i}{H_{old}}\right)$	$D_{abs} - \frac{1}{4} \sum_{i=1}^4 \arctan\left(\frac{Y_i + Y_c}{X_i + X_c}\right)$
H_{base}	$H_{old} - \frac{1}{4} \sum_{i=10}^{13} X_i$	$H_{new} = H_{new} - \frac{1}{4} \sum_{i=10}^{13} \sqrt{(X_i + X_c)^2 + (Y_i + Y_c)^2}$
Z_{base}	$Z_{old} - \frac{1}{4} \sum_{i=10}^{13} Z_i$	$Z_{new} - \frac{1}{4} \sum_{i=10}^{13} Z_i$
ΔH	—	$\Delta H = \frac{1}{4} \sum_{i=10}^{13} \sqrt{(X_i + X_c)^2 + (Y_i + Y_c)^2} - \frac{1}{4} \sum_{i=1}^4 \sqrt{(X_i + X_c)^2 + (Y_i + Y_c)^2}$
X_{base}	$H_{old} \cdot \cos(D_{abs}) - \frac{1}{4} \sum_{i=10}^{13} X_i$	$(H_{new} - \Delta H) \cdot \cos(D_{abs}) - \frac{1}{4} \sum_{i=1}^4 X_i$
Y_{base}	$H_{old} \cdot \sin(D_{abs}) - \frac{1}{4} \sum_{i=1}^4 Y_i$	$(H_{new} - \Delta H) \cdot \sin(D_{abs}) - \frac{1}{4} \sum_{i=1}^4 Y_i$
ΔF	—	$\frac{1}{18} \sum_{i=1}^{18} [\sqrt{(X_i + X_c)^2 + (Y_i + Y_c)^2 + (Z_i + Z_c)^2} - F_i] - P2 + P3$
$SO(D)$	—	$\frac{-1}{4} [D_1 - D_2 + D_3 - D_4] \cdot (H_{new} - \Delta H)$
$SO(I)$	—	$\frac{1}{4} [I_1 - I_2 - I_3 + I_4 + 2\pi] \cdot F_{new}$
δ	—	$\frac{1}{4} [D_1 + D_2 - D_3 - D_4]$
$\varepsilon(D)$	—	$\frac{1}{4} [D_1 - D_2 - D_3 + D_4 - 2\pi] \cdot \text{ctg}(I_{abs})$
$\varepsilon(I)$	—	$\frac{1}{4} [I_1 + I_2 - I_3 - I_4]$
ΔI	—	$\frac{1}{2} [I_1 - I_2 + I_3 - I_4]$
ΔF_{pillar}	—	$\frac{1}{10} \left(\sum_{i=1}^{10} T_i - \sum_{i=5}^9 F_i - \sum_{i=14}^{18} F_i \right) + P1 - P2$

Analysing the DI-magnetometer errors can help detect rough errors in measurements of the magnetic declination/inclination angles.

The equations for calculations according to old and new techniques are given in Table 2. To calculate separate components, equations are given in different colours according to the absolute measurements stages. In some equations, the components are highlighted in different colours. This indicates that the data are used from different stages of measurements, and the result may be unreliable due to disturbances in the geomagnetic field.

3 Results and discussion

A comparison of the baseline values of the LEMI-025 variometer obtained in the first half of 2022 was computed using the old and new methodologies, which are given in Tables 3 and 4. Every month the absolute

measurements were provided 1415 times. Table 3 presents the monthly averaged baseline value of each component. Both methods, on average, give consistent estimates of the baseline values – the deviation does not exceed ± 0.3 nT. Table 4 shows the standard deviations of the baseline values of each component during the corresponding month. The new technique provides a smaller deviation in the estimates of the baseline values.

The results of the ABS.exe program (using POS-1 data) and the new calculation technique also were compared. Table 5 shows the monthly averaged baseline values of each component. Both programs, on average, provide consistent estimates of the baseline values of components *X* and *Y* – the deviation does not exceed ± 0.3 nT. Average monthly estimates of the baseline values of component *Z* differ quite significantly in March, probably due to a higher level of geomagnetic fluctuations in this month. Table 6 shows that

Table 3. Comparison of average monthly base values of LEMI-025 calculated by old and new techniques (method A)

Date	Old technique			New technique			Difference		
	Xbold, nT	Ybold, nT	Zbold, nT	Xbnew, nT	Ybnew, nT	Zbnew, nT	dXb, nT	dYb, nT	dZb, nT
2022/01	19739.72	5576.68	-31878.82	19739.76	5576.72	-31878.63	-0.03	-0.04	-0.19
2022/02	19740.10	5576.36	-31878.64	19740.02	5576.29	-31878.36	0.08	0.07	-0.27
2022/03	19740.41	5576.27	-31878.11	19740.41	5576.01	-31878.19	0.00	0.26	0.08
2022/04	19741.23	5577.03	-31877.47	19741.42	5576.91	-31877.53	-0.19	0.12	0.06
2022/05	19742.27	5576.57	-31877.05	19742.49	5576.41	-31877.01	-0.21	0.15	-0.04
2022/06	19743.02	5578.67	-31876.36	19743.11	5578.62	-31876.41	-0.09	0.05	0.05

Table 4. Comparison of monthly standard deviations of LEMI-025 baseline values calculated by old and new techniques (method A)

Date	Old technique			New technique			Ratio		
	σ_{Xold} , nT	σ_{Yold} , nT	σ_{Zold} , nT	σ_{Xnew} , nT	σ_{Ynew} , nT	σ_{Znew} , nT	$\sigma_{Xold}/\sigma_{Xnew}$	$\sigma_{Yold}/\sigma_{Ynew}$	$\sigma_{Zold}/\sigma_{Znew}$
2022/01	0.54	1.13	0.95	0.36	0.59	0.33	1.49	1.90	2.89
2022/02	0.54	0.86	1.14	0.38	0.64	0.31	1.42	1.34	3.64
2022/03	0.56	0.57	0.63	0.34	0.62	0.17	1.66	0.91	3.81
2022/04	1.16	1.16	0.74	0.76	1.06	0.44	1.53	1.10	1.67
2022/05	0.64	1.26	0.44	0.43	1.21	0.36	1.50	1.04	1.21
2022/06	0.87	0.80	0.49	0.75	0.69	0.43	1.16	1.15	1.14

the standard deviations of the baseline values of component Z obtained by the ABS.exe program in March are much larger than those obtained by the new one.

The difference in the evaluations by different techniques is due to several reasons. The old and new processing techniques for absolute measurements (as well as the ABS.exe program) do not differ in the formulas (and estimates) for magnetic declination and inclination. There is a certain inconsistency in the estimates of the total intensity. According to the old technique, this parameter is calculated as the average value of two series of measurements before and after the measurements of the magnetic inclination angles. According to the new technique, the total intensity is the average reading of the absolute magnetometer exactly at the interval of the magnetic inclination measurements.

In practice, this discrepancy has a spread of -4.2 to 3.2 nT based on absolute measurements in January–June 2022. There are similar differences in the estimates of H_{abs} and Z_{abs} components, as these are calculated using the absolute total intensity F_{abs} .

The equations for calculating auxiliary baseline values H_{base} , D_{base} also differ significantly in both techniques. The calculations of the old technique seem more convenient for the variometer with the sensor oriented in the HDZ orientation, that is, when the X component is directed to the magnetic North, Z – down. In this case, the X channel of the variometer really measures the horizontal component of the magnetic field vector. Therefore, it is possible to calculate the baseline value as the difference between H_{abs} and X . Also, at such an orientation of the sensor, it is possible to estimate the magnetic declination based on the readings of the Y channel of the variometer and the value of H_{abs} at the same time interval. Note that in the formula of the old technique for estimating D_{base} , the values of D_{abs} and Y_i are taken at the interval of magnetic inclination measurements, and the absolute value of the horizontal component of the magnetic field vector is taken at the interval of magnetic inclination measurements.

Given that the observatory’s average value of the magnetic declination is about 15.5 degrees, applying

Table 5. Comparison of average monthly base values of LEMI-025, calculated according to the results of the ABS program and according to the new technique (method A)

Date	ABS program			New technique			Difference		
	$X_{b_{ABS}}$, nT	$Y_{b_{ABS}}$, nT	$Z_{b_{ABS}}$, nT	$X_{b_{new}}$, nT	$Y_{b_{new}}$, nT	$Z_{b_{new}}$, nT	dX_b , nT	dY_b , nT	dZ_b , nT
2022/03	19740.71	5576.10	-31878.95	19740.41	5576.01	-31878.19	0.30	0.08	-0.75
2022/04	19741.51	5576.93	-31877.83	19741.42	5576.91	-31877.53	0.09	0.02	-0.30
2022/05	19742.56	5576.44	-31877.25	19742.49	5576.41	-31877.01	0.07	0.02	-0.23
2022/06	19743.12	5578.63	-31876.52	19743.11	5578.62	-31876.41	0.02	0.01	-0.11

Table 6. Comparison of the monthly standard deviations of the LEMI-025 baseline values calculated by the results of the ABS program and by the new technique (method A)

Date	ABS Program			New technique			Ratio		
	$\sigma_{X_{ABS}}$, nT	$\sigma_{Y_{ABS}}$, nT	$\sigma_{Z_{ABS}}$, nT	$\sigma_{X_{new}}$, nT	$\sigma_{Y_{new}}$, nT	$\sigma_{Z_{new}}$, nT	$\sigma_{X_{ABS}}/\sigma_{X_{new}}$	$\sigma_{Y_{ABS}}/\sigma_{Y_{new}}$	$\sigma_{Z_{ABS}}/\sigma_{Z_{new}}$
2022/03	0.62	0.63	0.89	0.34	0.62	0.17	1.83	1.02	5.35
2022/04	1.16	1.11	0.95	0.76	1.06	0.44	1.52	1.05	2.16
2022/05	0.45	1.21	0.46	0.43	1.21	0.36	1.05	1.00	1.27
2022/06	0.77	0.69	0.73	0.75	0.69	0.43	1.02	0.99	1.70

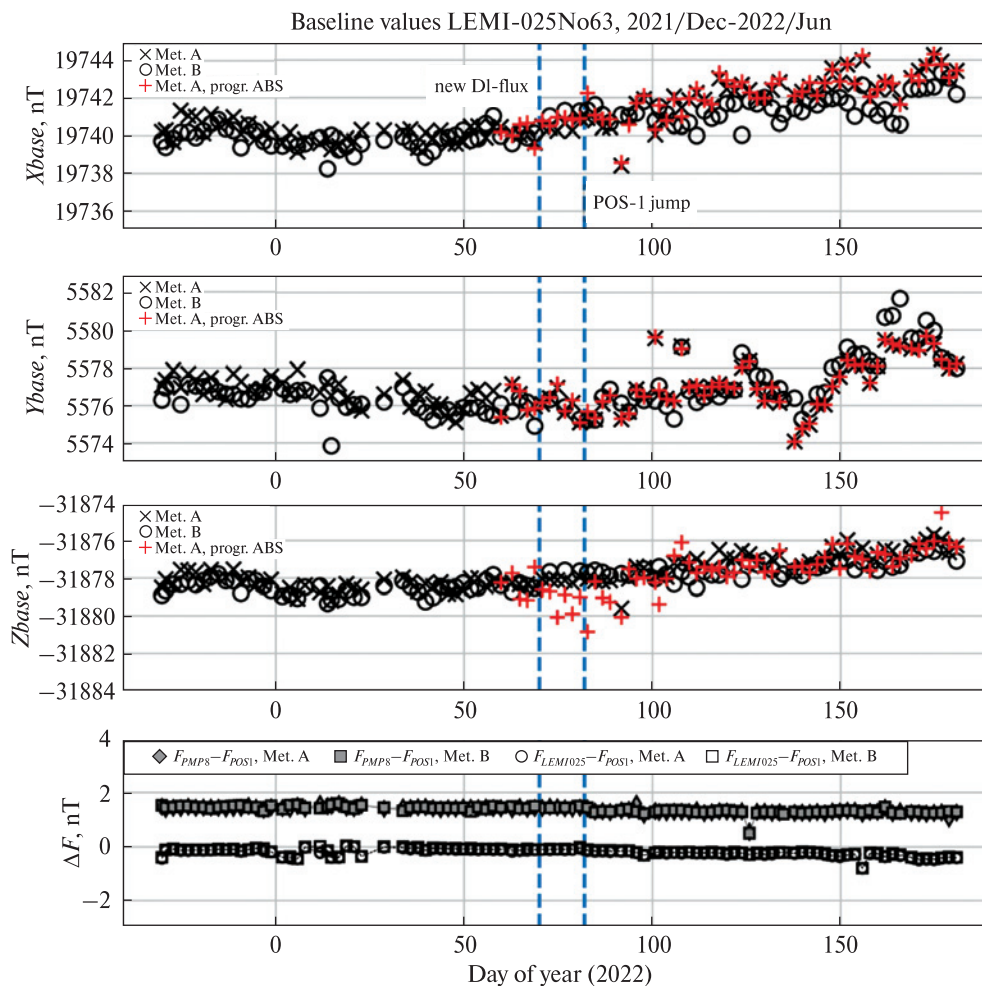


Figure 5. Baseline values of the LEMI-025 variometer (“x” and “o” – the new approach of data processing of absolute measurements taken by the zero and residual methods respectively; “+” – the ABS program applied to the zero method dataset)

the formulas of the old technique can lead to erroneous results. In the new technique, the magnetic inclination and the horizontal component of the mag-

netic vector are calculated based on the readings of the LEMI-025 variometer components compensation signals X_c , Y_c . The calculation of auxiliary base-

Table 7. Comparison of baseline values before and after replacing DI magnetometers

Parameter	Old DI magnetometer 09.02–11.03 2022		New DI magnetometer 12.03–13.04 2022		Difference	
	Method A	Method B	Method A	Method B	Method A	Method B
Xbase, nT	19740.06	19739.94	19740.57	19741.16	0.51	1.22
Ybase, nT	5576.18	5575.72	5576.21	5576.04	0.03	0.31
Zbase, nT	-31878.38	-31878.49	-31878.09	-31877.74	0.28	0.75
ΔF_{pillar} , nT	1.417	1.430	1.373	1.346	-0.043	-0.083

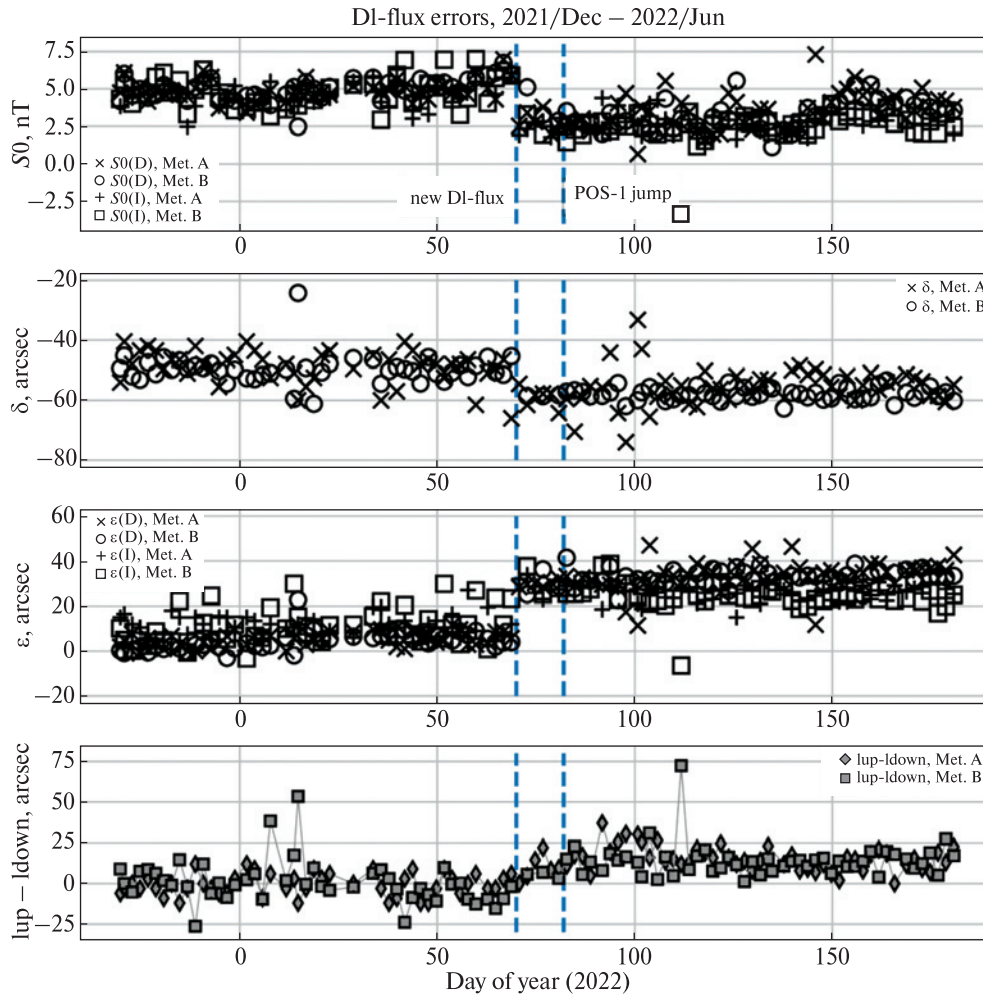


Figure 6. Errors of the old and new DI-magnetometers (see explanations of the symbols in the plot insets)

line values of both H_{base} and D_{base} takes place with the involvement of data at the same time intervals. Also, according to the new methodology, the difference value ΔH of the horizontal component of the magnetic vector is calculated at the time intervals of the magnetic inclination and declination measure-

ments. This difference was later used to bring the absolute value of the horizontal component of the magnetic vector to the time interval of declination measurements (t_1-t_4). It is required to determine the absolute values of the components X_{abs} , Y_{abs} , and the corresponding baseline values X_{base} , Y_{base} .

Table 8. Comparison of the ΔF_{pillar} difference before and after the removal of the old equipment 03/23/2022

Parameter	21.02–22.03 2022		23.03–23.04 2022		Difference	
	Method A	Method B	Method A	Method B	Method A	Method B
$\Delta F_{pillar}, nT$	1.425	1.435	1.334	1.314	-0.091	-0.122

The old technique for calculating these values uses the uncorrected absolute value of the horizontal component of the magnetic vector, which is obtained for the time interval of magnetic inclination measurements (t_{10} – t_{13}).

Graphs of the baseline values of the LEMI-025 variometer from December 2021 to June 2022 are shown in Figure 5. The results of measurements by methods A and B, calculated according to the new method, are marked in black. The results of method A calculated using the ABS.exe program are marked in red. Vertical dashed lines mark the moments of transition to a new DI magnetometer on March 12 and the removal of the old equipment on March 23 from the room where the POS-1 sensor magnetometer is installed, which caused a change in its records by +9.1 nT. The total field difference $\Delta F = F_{\text{LEMI025}} - F_{\text{POS1}}$ is calculated with the correction of POS-1 recording on $P3-P2 = 17.75$ nT in the interval until March 23 and $P3-P2 = -26.85$ nT after this date. The total field difference $\Delta F_{\text{pillar}} = F_{\text{PMP8}} - F_{\text{POS1}}$ is calculated with the correction $PI-P2 = -9.5$ nT before March 23 and $PI-P2 = -18.6$ nT after that date.

To assess the impact of the theodolite replacement, we compare the average baseline values at one-month intervals before/after March 12 (Table 7). The basic values obtained by method B have changed more significantly than those obtained by method A. The last line of the table shows the difference in signals of the scalar magnetometers PMP-8 and POS-1 – their change at the same time intervals insignificant (<0.1 nT) and cannot explain the change in baseline values. In order to confirm the proper correction of POS-1 readings, Table 8 shows the difference in signal ΔF_{pillar} for one-month intervals before/after March 23. The initial correction value of 9.1 nT substantially improves (within 0.12 nT) the change in POS-1 readings after the removal the old equipment from the room.

Error graphs of DI-magnetometers are shown in Figure 6. The new device has a slightly smaller sensor zero drift (3.0 nT instead of 4.8 nT) and slightly larger angular error values: $-59''$ instead of $-49''$ for the collimation error δ and $29''$ instead of $8''$ for the collimation error ϵ . Note that the measured errors of the new DI magnetometer exceed the values from the

technical documentation (zero drift <1 nT, collimation errors $<20''$). Clarifying the reasons for this inconsistency requires further research.

4 Conclusions

A new method for processing absolute measurements conducted at the geomagnetic observatory “Argentine Islands Archipelago” (AIA) of the Akademik Vernadsky station is proposed. Compared to the results of the other two procedures, the new approach (methodology) allows obtaining a significantly smaller (sometimes up to 4 times) spread of the baseline values, especially when conducting absolute observations at increased magnetic disturbances.

It should also be noted that the use of the new DI-magnetometer practically did not change the baseline values of the variometer in comparison with previous years, which indicates the reliability of the obtained results but significantly increased the convenience of conducting observations.

Therefore, the installation of new devices and the application of new calculation methods made it possible to ensure the quality and convenience of measurements at the station and obtain one-second data in the new INTERMAGNET format, as well as to improve the accuracy of absolute measurements carried out at the geomagnetic observatory.

Data availability. Not applicable.

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Підвищення точності абсолютних вимірювань у геомагнітній обсерваторії «Аргентинські острови» Української антарктичної станції «Академік Вернадський»

Реферат. В останні роки на геомагнітній обсерваторії «Аргентинські острови» Української антарктичної станції «Академік Вернадський», яка розміщена на острові Галіндез, модернізували обладнання. Завдяки цьому на обсерваторії встановлено нові прилади: базовий трикомпонентний ферозондовий магнітометр LEMI-025, однокомпонентний інклінометр-деклінометр Mag-01H із немагнітним теодолітом Wild T1 (DI-магнітометр) та скалярні магнітометри GSM-19 і GSM-90 на ефекті Овергаузера. Ці прилади мають високу роздільну здатність, що дозволяє проводити вимірювання з більшою точністю і застосовувати нові методи обробки варіаційних та абсолютних спостережень. Встановлення у 2022 р. нового DI-магнітометра практично не змінило базисних значень магнітоваріаційної станції LEMI-025 у порівнянні із попередніми роками, що свідчить про достовірність отриманих результатів, однак зробило проведення спостережень значно зручнішим. Наведено результати обробки абсолютних спостережень, які проводили різними методами. Описано різні методики обчислень цих спостережень, а також зазначено певні недоліки чи неточності при їх застосуванні. Запропоновано рекомендації для усунення виявлених недоліків. Здійснено порівнян-

ня результатів обробки абсолютних спостережень різними методиками та знайдено причину неузгодженості певних величин. Запропоновано нову методику обрахунку абсолютних спостережень, що використана на обсерваторії, яка показала досить якісні результати. У новій методиці започатковано обчислення похибок ДІ-магнітометра, а саме: зміщення нуля магнітного сенсора, колімаційної похибки азимуту δ і колімаційної похибки нахилу ϵ його осі чутливості відносно осей теодоліта. Аналіз цих похибок дозволяє ідентифікувати, а подекуди і виправити, грубі помилки при проведенні абсолютних вимірювань. Встановлення нових приладів та застосування нових методик обчислення дозволили забезпечити якість та зручність вимірювань на станції, автоматизувати процес обробки та підготовки даних для передачі в мережу INTERMAGNET, а також мінімізувати вплив людського фактору.

Ключові слова: абсолютні спостереження, геомагнітна обсерваторія, магнітне нахилення, схилення