

Review of "Noise in raw data of geomagnetic observatories" by S.Y. Khomutov et al.

REPLY TO THE Referee #1

Dear colleague,

5 we thank you for attention to our work and useful comments. We are sure that the corrections made by your comments will significantly improve the article. We use the following color conventions:

Text in Black color: Comments by Referee

Text in Blue color: Reply to the Comments

Text in Green color: New text in the Manuscript.

10 Comment (1): The paper needs considerable language improvement to grammar and style level as well as conciseness. I don't recommend publication until the authors have been working significantly on this. Pointing out all the necessary language corrections is beyond this review, and the list of special comments is addressing few of them. The manuscript needs careful attention, preferably from a native speaker. Some shortening should be possible in this process without loss of information.

15 Reply (1): We understand that the grammar and stylistics of the text of the article are not sufficiently verified with respect to the English language. We believe that this is a results of the method of preparing the article: the original text was prepared in the style of the common Russian scientific language. The next professional translation turned out to be close to "word-per-word" to the original, however it turned out far enough from the style of scientific English. We made
20 significant adjustments to grammar and stylistics at the preliminary stages of reviewing the article by the editor. Unfortunately, radical processing requires writing the text initially in the stylistics of scientific English, in fact by other authors, and this will be another article. We understand that the quality of work is reduced for these reasons. In part, we hope for an editorial revision in according to the "English language copy-editing for final revised papers" (https://www.geoscientific-instrumentation-methods-and-data-systems.net/for_authors/article_processing_charges.html).
25

Comment (2): The classification of types of noise presented in this paper includes some very special terms, which are not very common. Examples are 'regular-random noise', pulse-noise', These are not common expressions and should be better explained in the text or replaced by more common expressions like 'spike' if possible.

30 Reply (2): We took your comments into account, as far as possible. For example, instead of "pulse" we used "spike".

Comment (3): I think the word 'magnetologist' could be more clearly defined on page 2, line 11, as it is used throughout the text.

35 Reply (3): we use the term "magnetologist" for a specialist who make magnetic measurements and process the result of your measurements (raw data).

Text(3): At the same time, both the first, and the second types of papers are not often oriented to give practical recommendations to magnetologists, that is specialists at observatories, who directly

make magnetic measurements and process raw data.

Comment (4): You never used time derivatives of H, D, Z to visually identify small spikes. Why not? I think this is a very useful method to identify small artificial disturbances in the presence of larger natural field changes when you only have one recording instrument. It acts like a low pass filtering.

Reply (4): You're right. The analysis of derivatives of variations of H,D,Z is a very effective method, and in some cases the only one in the search for spikes. This method is used in our simple algorithms for identifying of isolated spikes, when two adjacent samples in the first differences should be close in amplitude and have opposite signs. However, the use of the derivatives for automatic identification of spikes is sometimes difficult, because it requires an adequate choice of the threshold value of the field change, when the pulse-like signal can be regarded as artificial. Therefore, I agree with you that analysis of derivatives is more productive with visualizing of data.

For example, we currently reprocess old digital magnetic measurements, in order to obtain minute data of the INTERMAGNET standard. Measurements of the variations dH , dD , dZ were performed only by single digital fluxgate magnetometer. Visual analysis of the first differences (derivatives) is a standard procedure for processing. Figure 1 shows the graphs that the magnetologist sees on the display during processing. The software finds the values of the first differences, which exceed the preset threshold $+0.3$ nT/sec and marks these places on the original variation curves, attracting the attention of the magnetologist to these places of recording.

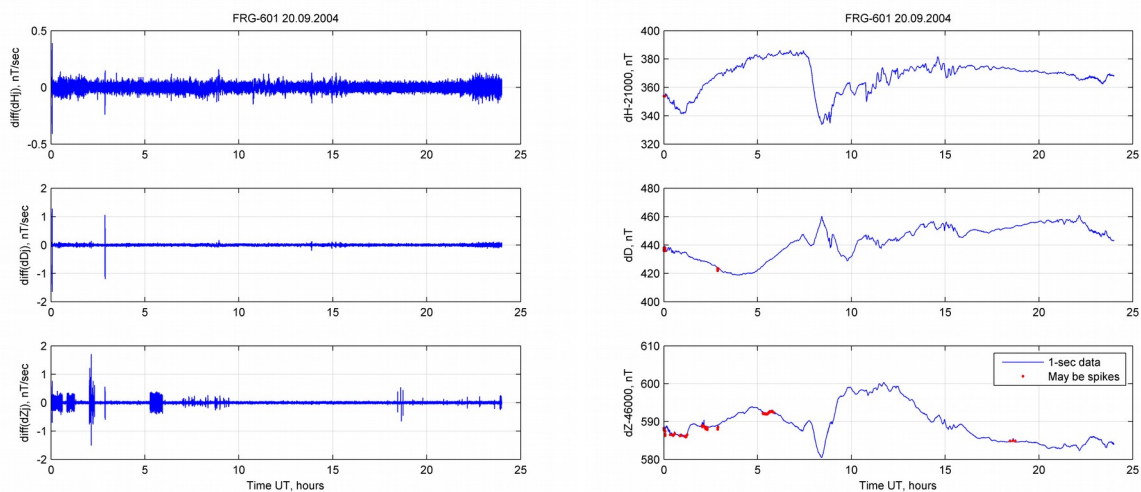


Figure 1. Left panel – first differences of variations dH , dD , dZ recorded by fluxgate magnetometer FRG-601 (sampling rate is 1 per sec). Right panel – initial record of variations, red dots mark the possible place of spikes.

Figure 2 shows some selected sections of the curves in Fig. 1 (right panel), which represent the nature of the signals with more details. Based on the analysis of the displayed data and other auxiliary information, the magnetologist decides what to do with the signals marked. Unfortunately, during magnetic disturbances the change of the field between neighboring measurements can exceed a given threshold and we get a lot of false marks. An example of such a situation is shown in Figure 3.

I am the person of the INTERMAGNET, who checks the Definitive data. At some observatories the

scalar magnetometer is not used and only data obtained using variation magnetometer are presented. In these cases, the analysis of the first differences is, in fact, the only way to detect the noise in the data. Of course, the analysis of minute data is much less efficient than the analysis of raw data, and noise in Declination is not detected at all by the differences $F(\text{var})$ - $F(\text{scal})$.

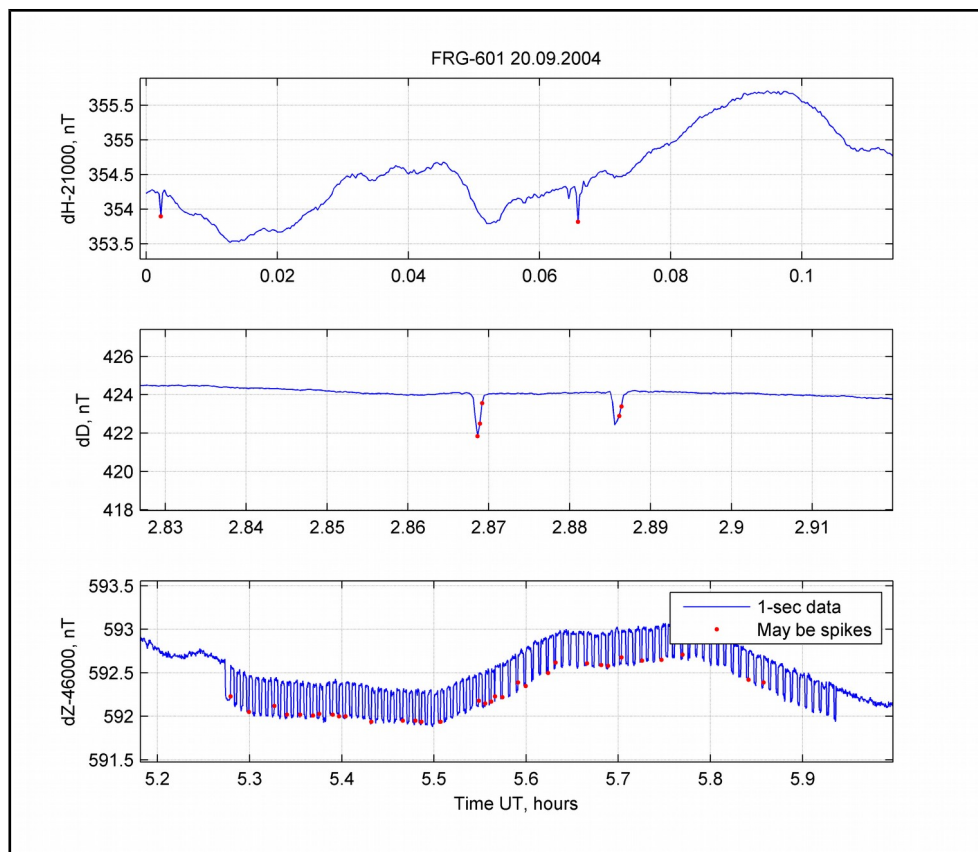


Figure 2. Some parts of records at Figure 1 (right panel).

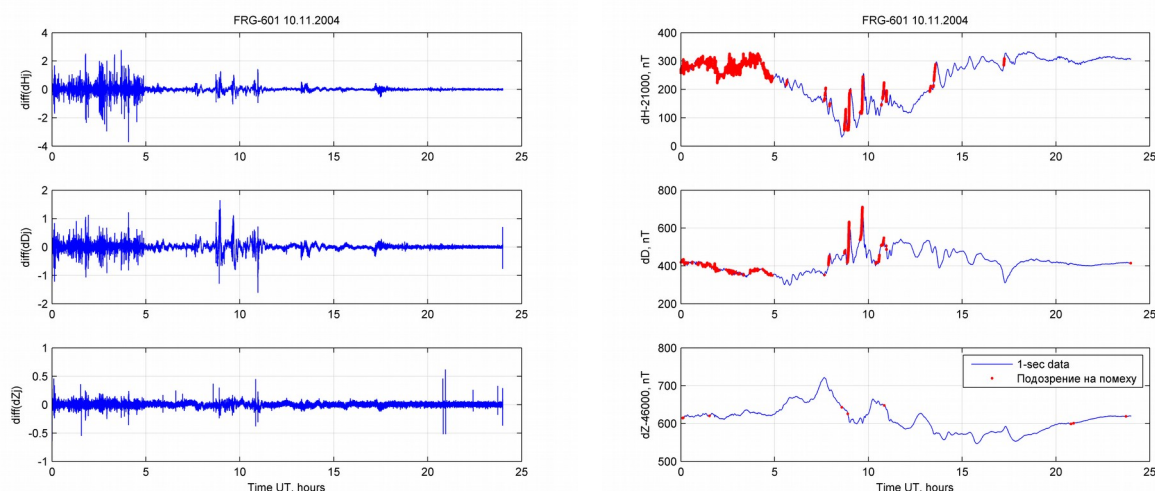


Figure 3. The same at Figure 1, but for 10 November, 2004, during strong magnetic storm.

Text(4): In many cases the visual control of the derivatives of magnetic field variations is effective tools to detect the spikes in recorded raw data. It is clear, that noise in the record shown in Fig. 4a

does not represent a problem for program processing, and in case of smaller quantity they can be processed manually.

Comment (5): The term 'noise' is singular; please don't write 'noises'. Either 'noise' or, if you want to express plural, use terms like 'types of noise' or 'forms of noise'.

80 Reply(5): we changed "noises" to "noise" over text

Comment (6): page 1 line 11 word centres -> World Data Centres

Reply(6): we had in mind that not only WDCs distribute the magnetic data. For example, INTERMAGNET give the access to magnetic data with Reported, Adjusted and Quasi-Definitive status.

85 Text(6): ... the quality of magnetic data accessible through the data centres (for example, World Data Centres or INTERMAGNET) still largely depends on the actual conditions...

Comment (7): 1. 12 primary results -> raw data?

Reply(7): Done

90 Text(7): Processing of raw data of magnetic measurements by observatory staff plays an important role

Comment (8): 1. 19 upper shells -> lithosphere? near Earth space?

Reply(8): Done

95 Text(8): Magnetic measurements at observatories are an important source of information to study the processes in the Earth's interior and near Earth's environment that substantially supplements the data obtained from satellites...

100 Comment (9): 1. 22 to 27 Not sure what is meant and I likely disagree: by giving rules for variational data, INTERMAGNET is effectively giving rules raw data. Every observatory has to submit 1 year of data (minute means from variometer) to become accepted as INTERMAGNET observatory. In this process, the data is checked by experts. Possibly, the authors want to address mean minute means (variational data) and higher resolution spot readings (raw data)? This is now addressed in 1-second data of INTERMAGNET.

Reply(9): INTERMAGNET Technical Reference Manual (ver.4.6) in section 2.1 Specification give for vector magnetometers

Vector Magnetometer

105 Resolution: 0.1 nT
Dynamic Range: 8000 nT High Latitude
6000 nT Mid/Equatorial Latitude
Band pass: D.C. to 0.1 Hz
Sampling rate: 1 Hz

110 Thermal stability: 0.25 nT/EC
Long term stability: 5 nT/year

115 That is all... Some recommendations for good quality are described at page 7. Term "noise" in Manual is found only once, term "quality" is found, may be, near ten times. I agree with you, that INTERMAGNET set strong rule of the process of calculation of the minute data with different status. 3-stage control of preparation of the Definitive data is unique and very effective "technology" of INTERMAGNET. It is my private experience, because during many years I am INTERMAGNET checking person, who check the Definitive data at stage 1.

120 But I see, that the good magnetometers and following to measurement standards do not solve the problems with noise in the raw data. Moreover, in some case, 3-level checking of minute Definitive data do not remove the possible errors, that are arisen in raw data and come to Definitive data, if observatory don't make the correct processing of noisy data.

Comment (10): 1. 27 What is primary magnetic measurementns?

Reply(10): This is our mistake. We meant the primary (raw) results of magnetic measurements. Text is corrected.

125 Text(10): Final data of INTERMAGNET observatories (quasi-definitive and definitive) undergo multistage control, but their validity and reliability greatly depend on the quality of the results of magnetic measurements.

Comment (11): page 2 l. 5 noises -> noise registered -> recorded

Reply(11): Done

130 Text(11): In the result of influence of many external sources, noise manifest as signals in the magnetic field which are recorded by magnetometers.

Comment (12): 1. 11 oriented to -> targeted at OR aimed at

Reply(12): Done

135 Text(12): At the same time, both the first, and the second types of papers are not often given the practical recommendations to magnetologists, that is specialists at observatories, who directly make magnetic measurements and process raw data.

Comment (13): page 3 l. 5 conventionallyconsidered -> conventionally considered

Reply(13): Done

140 Text(13): ... the signals, which have sources closer than a few tens of kilometers, can be conventionally considered as noise...

Comment (14): Table 1 Please introduce space between the column for longitude and the column for institute. Please give a short description of the instruments used, especially when such information is not available from a current vendor website or manual. I personally don't know the

FGR-601, the Quartz-06 (Bobrov-type?), as the difference between POS-1 and POS-4.

145 Reply(14): we separated the columns in Table 1 and also we gave a brief description of magnetometers from Table 1

Text(14):

Remarks:

150 1) **GSM-90** (<http://www.gemsys.ca/scalar-magnetometers/>), **GSM-19** (<http://www.gemsys.ca/rugged-overhauser-magnetometer/>) and **POS-1** (<http://magnetometer.ur.ru/content/view/15/30/lang.en/>) are scalar Overhauser magnetometers;
2) **dIdD GSM-19FD** (<http://www.gemsys.ca/vector-magnetometers/>) and **POS-4** (Sapunov et al., 2016) are vector magnetometers with Overhauser sensor in coil system;
155 3) **MAGDAS** (MAGDAS-A Installation Manual, 2005), **FRG-601** (3 component fluxgate magnetometer FRG-601G, 2002), **FGE** (http://www.space.dtu.dk/english/research/instruments_systems_methods/3-axis_fluxgate_magnetometer_model_fgm-fge) and **GEOMAG-02M** (Nelapatla et al., 2017) are fluxgate magnetometers;
4) **Quartz-06** is magnetometer with Bobrov's quartz sensors (IZMIRAN, Moscow).

160 Comment (15): p. 9 l. 10 Does 'well-defined sharp leading and back edges' not also describe the features in Fig. 2 pretty well? But noise in Fig. 2 is supposed to be very different from noise in Fig. 4, I don't see the difference here very clearly. Please improve argumentation and possibly structure of the paper.

Reply(15): The noise on Fig. 2 (right panel) and in Fig. 4 are very similar, since both are shown as spikes. Nevertheless, there are very important differences:

165 1) Fig. 2 and Fig. 4 are presented in different sections of article describing different noise properties: Fig. 2 illustrates noise that is regularly repeated, i.e., noise with features in time (repeatability), and Fig. 4 shows spikes, i.e. noise with a certain internal structure;

170 2) because of the properties (1), different methods of detection and removing this noise are used: the noise on Fig. 2 is detected and removed using its regular time intervals, the noise on Fig. 4 are detected as irregular isolated spikes;

In addition, the noise from the ionosonde on Fig. 2 (right panel) actually has a more complex structure than spikes (for example, extended fronts) and can not always be distinguished by methods that effectively find spikes.

175 We think that it is not necessary to give an additional description of the differences in the interference in Fig. 2 and Fig. 4 or to change the structure of the text.

Comment (16): 1. 13 amplitude in units, tens and more of nanotesla -> amplitudes of tens of nanotesla or more

Reply(16): Done

180 Text(16): Spikes with amplitudes of tens of nanotesla or more also have a low probability of being caused by natural sources.

Comment (17): 1. 21-22 This sentence is very difficult to understand. Please reword. This is just one example of a sentence that has to be reworded to become understandable. Please check your manuscript and make sure it contains only sentences that can be clearly understood.

Reply(17): we changed the text

185 Text(17): Therefore, it is not difficult to identify and to locate them. The results of the using of simple method of the spike detection are shown on Fig. 4b.

Comment (18): 1. 25 This sentence is very difficult to understand. Please reword. This is just one example of a sentence that has to be reworded to become understandable. Please check your manuscript and make sure it contains only sentences that can be clearly understood.

190 Reply(18): we changed the text

Text(18): It should be noted that in the Overhauser magnetometers POS-1, which are quite widely distributed at magnetic observatories, each record is accompanied by the estimation of measurement quality using a special parameter QMC (Quality Measurement Criterion). QMC value is related to the quality of the proton precession signal and gives the qualitative estimates of measurement conditions such as signal-to-noise ratio, the duration of the precession signal, power supply voltage, etc. (POS-1 User manual, 2004; Denisov et al., 2006).

Comment (19): p. 10 1.5 This sentence is very difficult to understand. Please reword. This is just one example of a sentence that has to be reworded to become understandable. Please check your manuscript and make sure it contains only sentences that can be clearly understood.

200 Reply(19): we removed this sentence

Text(19): ...which are often extended in time and can have multimode structure.
Figure 5 shows the daily record of...

Comment (20): Figure 5: Why is only the Z-component affected. Can this be explained by the source of the disturbance? (Noise in the Z-component indicates that there is a horizontal cable with DC somewhere, noise in the horizontal components indicates that there is a current sheet in the ground below the instrument.).

210 Reply(20): This noise appeared after the construction of the subway in Hyderabad and is probably related to the operation of the underground infrastructure. They are observed in the records of all magnetometers that are installed at the observatory. The effect is not direct, because at night the metro does not work, however, spikes are preserved. Detailed studies were not performed, both statistical and experimental.

Comment (21): p. 12 1.1 dependent from -> dependent on the

Reply(21): Done

Text(21): The geomagnetic variations and noise are dependent on the location of the observatory.

215 Comment (22): 1. 13, 1. 20 This sentence is very difficult to understand. Please reword. This is just one example of a sentence that has to be reworded to become understandable. Please check your manuscript and make sure it contains only sentences that can be clearly understood.

Reply(22): Done

Text(22):
 220 L13:
 But spikes with small amplitude (<0.5 nT), which are 25% from all spikes, can not be reliably detected by magnetologists (experts) and can not be used for the estimation of the algorithm effectiveness. This also restricts the possibilities for the optimization of the algorithm of the detection of the small spikes.

225 L20:
 However, unlike spikes, in practice such jumps are quite rare in raw magnetic data (for example, Fig. 2). Jumps of magnetic record level with slow changed edges or with noisy edges are predominantly observed. The reasons of such jumps are the technical operations with equipment, the changes of the magnetic field distribution in the pavilion or near it, the changes of the instrument parameters, etc.

230

Comment (23): 1. 23 caused by the magnetic environment changes -> caused by changes in the magnetic environment

Reply(23): Done

Text(23): An example of noise in the form of jumps caused by changes in the magnetic environment near the pavilions at Paratunka observatory is shown in Fig. 6.

235

Comment (24): p. 13 l. 10 spaced -> separated

Reply(24): Done

Text(24): (b) such signals can be identified reliably only in difference data obtained by separated magnetometers;

240

Comment (25): 1. 16 jump noise -> jumps into the well -> into a well

Reply(25): Done

Text(25): Figure 6. Example of magnetic field jumps at Paratunka observatory during removal and lowering of casing steel pipe into a well of 80 m depth.

245

Comment (26): p. 14 l. 1 and 2 Similar anthropogenic disturbances are practically not corrected ...including noises is just removed -> Such anthropogenic disturbances are usually not corrected ...including the noise is removed.

Reply(26): Done

Text(26): ...out at that time. Such anthropogenic disturbances are usually not corrected and in most cases the record including the noise is removed.

250

Comment (27): p. 15 l. 5 This sentence is very difficult to understand. Please reword. This is just one example of a sentence that has to be reworded to become understandable. This is a typical example for a sentence which can be understood if you are familiar with the concept beforehand.

But I think it is very difficult to understand the meaning from scratch. In this situation, the wording should be more precise.

255 Reply(27): we removed this sentence

Text(27): It should be noted that the jumps, after which the record level is changed and retained for a long time (several days or longer, for example, after magnetometer reinstallation), are appeared in the baseline values of the variometers and they are eliminated during calculation of the total field vector using the standard measurement technology at magnetic observatories (see also some
260 remarks in Sect. 4).

Comment (28): 1. 8 I don't like the expression 'bay' here as it is normally used for the natural signal of the polar electrojet in auroral and subauroral stations, and not for man-made disturbances. Please use 'bay-like noise' or use a completely different term.

265 Reply(28): You are right, term "bay" is used for description of specific shape of natural magnetic signals. But artificial magnetic signal, e.g. from moving car, also can have the shape of bay. We will use term "bay-like noise".

Comment (29): 1. 10 What does this mean: 'are specific and connected among themselves'?

270 Reply(29): If some "magnet" move near magnetometer, it make the variations of field, recorded by magnetometer. These variations are smoothed and have the definite shape, usually "bay-like" shape (see Figure 8, for example). We named these shape as "specific". Moreover, the variations in H-, D- and Z-components, produced by moved "magnet", can not have arbitrary shapes. The shapes of dH,dD,dZ signals are related, because are results from the same magnetic dipole with fixed moment. So, we changed the text

275 Text(29): In case of such noise, shapes of signals in the field components are defined and related. Nevertheless...

Comment (30): 1. 20 What does this mean: 'their time shift is clearly defined'?

280 Reply(30): Because the magnetometers are installed in two pavilions at distance of about 30 meters, the moved car will make similar magnetic signals, but slightly shifted by time. We can see this at Figure 8 as shift in position of extremes of bay-like signals. This is argument that our signal are results of moving car.

Text(30): The distance between the pavilions is about 30 m. Noise duration is about 30-40 s, the amplitude is up to 20-30 nT, the time shift between signals recorded by magnetometers in two remote pavilions is clearly defined.

285 Comment (31): 1. 21 and 22 Please note that in general for mid and high latitude on the northern hemisphere, magnetic field sources that move in the horizontal plane around the magnetometer are giving strong negative disturbances in Z while they give disturbances in both direction in the horizontal components. This supports your argument.

Reply(31): Yes, you are right. Thank you. As example – we see two small bay-like negative signals

290 in Z at our old digital magnetic records. Because data was recorded many years ago, no one say
about reasons of these anomalies. We assume that is effect of opening and closing of the outer door
of the variometer hut: some magnetic elements on door move with door.

Comment (32): p. 17 l. 1 I am not sure why this phenomena is called 'randol-like' noise. Figure 9 I
would call artificially disturbed, while Fig. 10 I would call 'noisy'.

295 Reply(32): Yes, noise on Figure 9 is isolated artificial signal, but noise at Figure 10 is similar to
random signal. If noise can not isolated by time, has no defined structure or shape – we can say that
is random-like noise.

Comment (33): p. 18 l. 12 problems with the -> faulty power supply

Reply(33): Done

Text(33): Noise-like interference caused by the faulty power supply at Khabarovsk observatory,

300 Comment (34): p. 19 l. 10 researches which are -> the research that is

Reply(34): Done

Text(34): This criterion is important due to the fact that it determines the extent of noise influence
in magnetic data on the results of research that is carried out using these data.

Comment (35): l. 10 to 11 remove 'published in some way'

305 Reply(35): Done

Text(35): When a researcher uses the final data from observatories, in most cases he has no
information in what conditions the measurements were performed...

Comment (36): l. 13 to scientific -> to the scientific lies on an -> lies on the

Reply(36): Done

310 Text(36): Thus, the responsibility for the quality of the data provided to the scientific community is
very high and it completely lies on the observatory.

Comment (37): l. 16 of INTERMAGNET -> of the INTERMAGNET

Reply(37): Done

315 Text(37): An observatory of the INTERMAGNET network obtains primary 1-second data of dHs,
dDs, dZs, Fs variations ...

Comment (38): l. 17 reduced to main -> reduced to the main

Reply(38): Done

- Text(38): ...using baseline values, calculates total Hs, Ds, Zs, Fs, reduced to the main pillar, and minute values Hm, Dm, Zm, Fm using the procedure defined by INTERMAGNET standards...
- 320 Comment (39): 1. 18 procedure, defined -> procedure defined
- Reply(39): Done
- Text(39): see Text(38)
- Comment (40): 1. 20 bays -> bay-like artificial disturbances
- Reply(40): Done
- 325 Text(40): Also Gaussian filtering works acceptably with spikes of small amplitude, but it is not effective for jumps and bay-like noise.
- Comment (41): p. 20 l. 1 these critical noises and to remove them -> such critical noise and to remove it
- Reply(41): Done
- 330 Text(41): That makes it necessary to identify such critical noise and to remove it during the primary data processing.
- Comment (42): 1. 3 of INTERMAGNET recommendation, that -> of the INTERMAGNET recommendation that
- Reply(42): Done
- 335 Text(42): In spite of the INTERMAGNET recommendation that mean values should be calculated in accordance with the 90% availability rule, such rule is difficult to define and sometimes they are not applicable at all.
- Comment (43): 1. 4 What does the term 'criteria' refer to?
- Reply(43): Term "criteria" is synonym of term "rule" in this case. We changed the sentence.
- 340 Text(43): see Text(42)
- Comment (44): 1. 6 some reasons -> some sources
- Reply(44): Done
- Text(44): If it is known that a signal, which is suspected as a noise, is the result of some sources which are not associated with natural variations of magnetic field
- 345 Comment (45): 1. 15, 1st sentence please rewrite this sentence

Reply(45): We changed the sentence.

Text(45): (b) problems which are solved using the final data should be defined. Some signals can be as noise due to the criteria of its origin. But at the same time these signals can be the subject of other scientific research. For example, in practice of observatory

350 Comment (46): 1. 27 benchmark

Reply(46): Done

Text(46): However, if, for example, seismomagnetic effects are investigated, then the recorded "fictitious" signals in Fig. 12 would be a good benchmark to estimate the passage of a seismic wave in the area where magnetometers are installed.

355 Comment (47): 1. 29 please rewrite this sentence

Reply(47): Done

Text(47): Unfortunately, it is necessary to note that in some cases, the researchers of seismic effects in the magnetic field even do not ask what type of a magnetometer is, the data from which they use. Therefore, the researcher of seismomagnetic effects should understand well, what type of magnetometer is used to obtain magnetic data.

360

Comment (48): p. 21 l. 11 to 13 This is very good information. I think this information should be moved to the front of part 3.

Reply(48): We moved this paragraph to end of Introduction

Text(48): In this work we will classified noise, which are encountered the most frequently in actual magnetic measurements at the observatories of IKIR FEB RAS and CSIR-NGR, and illustrated them by some characteristic examples. Naturally, the description and the samples are quite limited, since the variety of noise is extremely large. We will consider only the noise, the man-made nature of which has already been proved or its structure allows us to interpret them unambiguously. Magnetic signals with features of noise, but with unknown sources, will be out of scope of this work. The data used in this paper were processed by the tools of MATLAB mathematical software package (www.mathworks.com) and by application software applied in MATLAB and Octave (http://www.gnu.org/software/octave/) environments used at observatories.

370

Comment (49): p. 22 l. 2 missing bracket ')'

Reply(49): Done

375 Text(49): (for example, POS-1 User manual (2004) and dIdD Instruction Manual (2010)),

Comment (50): p. 25 l. 14 Automatic program identification and correction of noise have an -> Automatic identification and correction of noise by computer programs are of

Reply(50): Done

380 Text(50): 3) automatic identification and correction of noise by computer programs are of auxiliary nature and are principally an interactive tools to help a magnetologist in data processing.

Comment (51): 1. 19 The similar -> A similar

Reply(51): Done

Text(51): A similar opinion is presented by Linthe et al. (2012).

Comment (52): 1. 25 can be solved ineffectively -> can become more difficult to be solved

385 Reply(52): Done

Text(52): At the same time, a part of the problems, including those connected with incorrect noise processing can become more difficult to be solved.

Comment (53): 1. 33 many-year discussion -> discussions over many years

Reply(53): Done

390 Text(53): ...are acknowledged for helpful discussions over many years, which improved our understanding of noise in magnetic observations.

With my best regards,
Sergey Khomutov