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Methodological and Software Approaches to Processing of Magnetic Measurements at Observatories of IKIR FEB RAS, Russia

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ABSTRACT

Main methodological principles of the softwares used for processing the data of magnetic observatories of IKIR FEB RAS, Far East, Russia are presented, which are prepared using mathematical package MATLAB and Octave as set of scripts and functions with open code. The ultimate goal of the processing steps is to achieve the full vector of the magnetic field at every minute, including reported and adjusted data calculation. The softwares are designed so that: (a) visualization of data during all steps of processing is available; (b) intermediate files of partially processed data are not produced, only primary data are used during any step of processing, the additional procedures, such as noise removing, temperature correction accounting and so on, are used as separate modulus and files. The processing steps have been applied to data of different magnetometers to establish robustness of the method. The block diagrams of magnetic data processing and the examples of service files and screenshots are presented.

Keywords: Magnetic Observatory, Software, Magnetic data processing.

INTRODUCTION

The magnetic data obtained at magnetic observatories (MOs) are very important for fundamental and applied sciences. MOs are connected to world observational networks with specified standards of high quality data. At present, the INTERMAGNET is the most significant network of MOs (see *INTERMAGNET Technical reference manual, 2012*). The high standards of the specifications of the magnetometers, the method of the measurements and formats of the resulting data are defined for INTERMAGNET observatories (IMOs). But methods, algorithms and software of the data processing adopted at each IMO are defined by individual observatories; there are no set standards for these procedures.

Recent publications, including the presentations at IAGA 2014 Workshop in Hyderabad (XVI IAGA Workshop, 2014), have shown that the prospects of having system of completely automated measurements at IMOs seem unlikely in near future. Therefore the current system of magnetic observations in accordance with INTERMAGNET standards is continued. In absence of unified and standardized method for processing and analysis of the data obtained by IMOs, it is difficult to ensure delivery of uniform quality of quasi-definitive and definitive data for all IMOs, especially for organizations that have several IMOs and for IMOs in remote locations without a full team of observatory scientists. Transmission of data in near real time is a priority of INTERMAGNET, which is easily achievable with today's technology of telecommunication. But the gaps in the "IMO – GIN" link are clearly visible due to lack of effective and user-friendly software, which may be used directly at IMOs.

The Institute of Cosmophysical Research and Radio Wave Propagation of the Far Eastern Branch of Russian Academy of Science (IKIR FEB RAS) have four magnetic observatories located at the Far East in wide range of the latitude (see Table 1). Three of these MO are observatories of the INTERMAGNET. MOs are equipped by modern vector and scalar (FGE DTU, GSM-90, GEM dIdD, POS-4) and absolute (DIflux LEMI-203, MAG-01H, POS-1, GSM-19W) magnetometers and systems for current and definitive processing of the data.

ALGORITHMIC AND SOFTWARE REALIZATION

MATLAB (and similar free package Octave) is used as the platform for the data processing software presented here. The software packages provide a scripting environment; the advantage of text format scripts being that they can be easily modified for the unique configuration of each observatory. MATLAB have expanded possibilities of the graphics that is very important for the visualization of data. Some standard tools, which allow read/write of wide variety of data formats and sufficient memory for large datasets are additional advantages of these platforms. In software of IKIR MOs we used only command window mode, without any visual-like applications.

Because all four observatories are divisions of the single institute, there is no problem with unification of the software - almost all of the modules, scripts and files have the same structure. Differences arise mainly because of differences in hardware used: each type of magnetometer generate unique

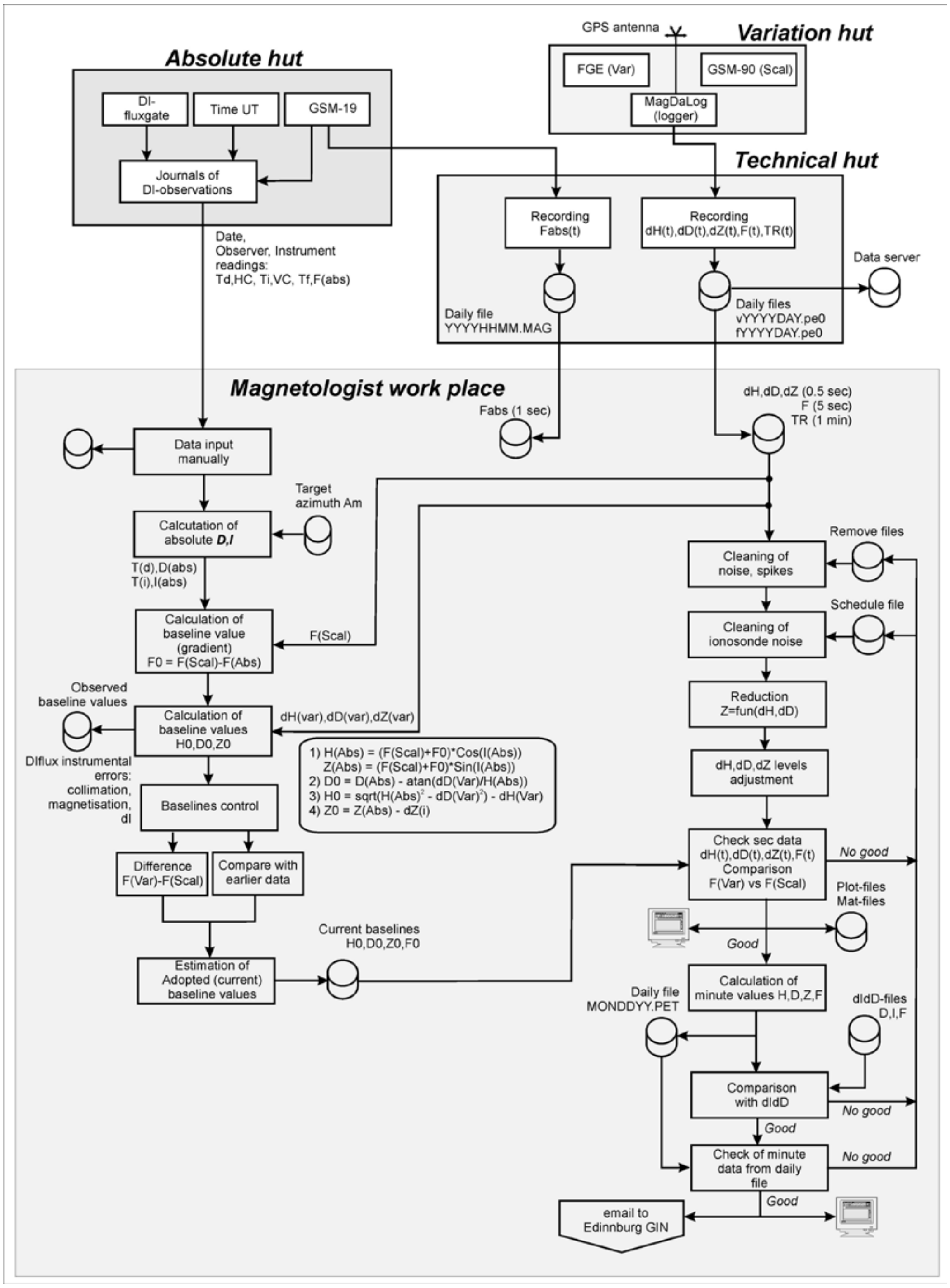

Figure 1. Diagram of the processing of the magnetic data of the main vector magnetometer FGE at observatory "Paratunka"

Table 1. The observatories of IKIR FEB RAS, the Far East, Russia

Observatory	Year	IAGA	IMO	Geograph		Geomag	
Cape Schmidt (Chukotka)	1967	CPS	No	68.9	180.6	64.0	231.5
Magadan (Stekolniy)	1965	MGD	2009	60.1	150.7	52.0	213.1
Paratunka (Kamchatka)	1968	PET	2013	53.0	158.3	45.8	221.5
Khabarovsk (Zabaykalskoe)	1968	KHB	2013	47.7	134.7	38.4	202.5

types of raw data files. For example there are significant differences for the HDZ-variometer (eg, FGE-DTU) and FDI-variometer (dIdD GSM-19FD). However, for the same type of devices the software is almost identical, for example, for the fluxgate FGE and MAGDAS. There are also differences in processing the results of the absolute observations, depending on the used magnetometers and techniques.

The general scheme for processing of magnetic measurements (by FGE only, as example) is presented at Figure 1. Most of the steps are routine in observatory practice. A few additional blocks will be explained in the main section of the article. The block "Reduction of Z=fun(dH,dD)" is used to remove the dependence of component Z from variations of horizontal components dH (about 1.3%) and dD (about 0.1%); the possible reason of this dependence is non-orthogonality of sensor Z to horizontal plane. The block ""Journals of DI-observations" means hand-filled form of observations, with readings of vertical (HC) and horizontal (VC) circles of a theodolite and values of total field F.

THE MAIN PRINCIPLES

Long experience of practical work at MOs, the standards and manual of INTERMAGNET and interaction with colleagues have allowed us to identify some principles, which can be used for methodical structuring of software (s/w) to be used at IMOs.

(1) Processing of the results of the measurements must be performed directly at the observatory, directly after the measurements, and by the staff of the observatory (magnetologists)

This approach enforces quick detection of problems with the magnetic measurements and quick estimation of the situation at the observatory in order to plan and take appropriate and effective solutions. The most common problem that arises is the lack of qualified personnel. However, if the observatory meets INTERMAGNET standards, i.e. there is good control of the basic operating environment of the variometer, then the work requirements on staff is minimised and staff with the necessary skills are more likely to be available.

(2) Input file for any stage of processing should be the primary data; creation and use of files of intermediate data should be kept to a minimum

The ordinary practice during the processing of magnetic data (for example, the calculation of the minute values of different status) generates a large number of intermediate files after execution of each step often simply due to changes of format, which are not explicitly tagged as output. For example, the application of the temperature corrections to the raw data file FILE0 leads to the creation of FILE1, next removing of noise - to FILE2, the adoption of the baseline values - to FILE3, etc. An alternative would be to use the transparent processing, where each procedure (temperature correction, obtaining of total field components, etc.) is one of consecutive and mandatory phases of the script. Thus intermediate files generated, will reside only in the computer's memory and output files contain only final results. In our s/w the script reads the original data at each stage of processing; the information to initialise each step is stored in the script itself.

The efficacy of this approach can be illustrated by the processing of the measurements of the main fluxgate vector magnetometer FGE to remove large amplitude noise recorded during occurrence of strong earthquakes (see module "Cleaning of noise, spikes" at Figure 1). Because the FGE sensors are suspended by a gimbaled joint, seismic movement of the pillar swings the sensors, introducing artificial signal to the magnetic data. Figure 2 show a part of record of D component during 19 May, 2013, which shows the effects of an earthquake of magnitude 6.5 at distance of 340 km from IMO PET (Paratunka), Kamchatka. The effects of the aftershocks are also visible in the magnetic data. It is clear that these oscillations with amplitude up to 100 nT must be removed. The magnetologist visually estimate the time interval of the earthquake effect from the plots and note to special text file the record similar "2013 05 19 18.6948 18.8508 111", where it is pointed the date, started and finish times of the interval and flags of applicability to the H,D,Z components. After restarting, the script reads this record and flags the data (in memory) with the symbol NaN (Not-a-Number) to indicate that these data aren't to be used during the next steps of processing. The effects are visible as a gap in the plot of Figure 2. For the next earthquake the new line "2013 05 19 19.3648 19.4154 111" are added to the file and so on.

This technique can be applied for removal of regularly recurring noise. For example, during the vertical sounding of the ionosphere by the ionosonde placed at the distance about 300 meters from magnetometers, there may be the pulses up to 1-2 nT in FGE data. The repetition of the sounding is 15 minutes. Figure 3 show the differences F(var)-F(scal) with clearly visible spikes. The procedure of the removing of this noise (see module "Cleaning of ionosonde noise" at Figure 1) use the information from special file with records similar to "2013 05 18 00 00 00 2013 05 20 23 59 59 15 +042 +049", where date and time of the beginning and ending of the sounding, interval between sessions (in minutes) and beginning and ending of the noise interval (in seconds) relatively to sounding session start time are presented; for example, the magnetic data during 14:45:42-14:45:49, 19 May, 2013 will be replaced by NaNs. The results are presented at Figure 3 (middle and lower panels).

Another example of this approach can be the correction

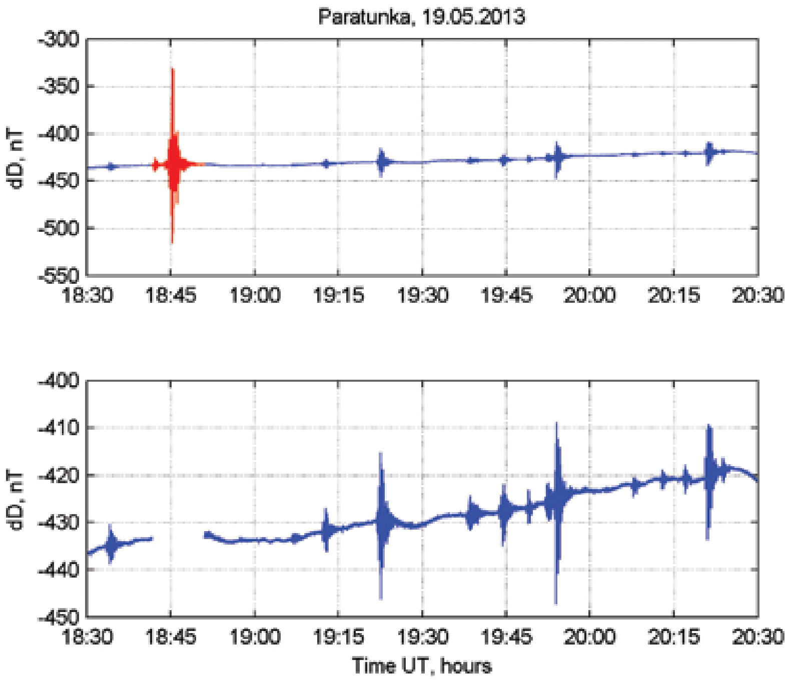

Figure 2. The example of the removing of the earthquake effect on the suspended fluxgate sensors during earthquakes. Upper panel: initial record; lower panel – record with the removed main shock effect.

of jumps in records (see module "dH,dD,dD levels adjustment" at Figure 1). The shifting of the data by the appropriate constant value allows to fix the problem. Figure 4 shows the part of the records of D components of the fluxgate FGE, when after the earthquake of February 19, 2015 levels of all components were changed. The information in special file with lines similar "2015 02 19 16 33 20 2015 02 19 23 59 59 -02.32 +01.470 +01.00 +00.00", where the start and finish of the corrected interval and values of shifting are presented, is used by script. The initial and resulting plots are shown at Figure 4.

(3) Routine processing, nominally everyday, must generate data with the status close to quasi-definitive, i.e. taking into account the real baselines and after removing of the noise

Efforts made to achieve high quality, near quasi-definitive data at the end of each day will necessarily have several benefits including generation of good quality quasi-definitive and definitive data very quickly

- the estimation of the current (adopted) baseline values would be performed almost immediately after the absolute observations to provide "real-time" control of the quality of the absolute observations and quality of the baselines
- generation of total field vector time series for different magnetometers for effective comparison between heterogeneous data that can be used to quickly identify potential problems
- filling of gaps with data from backup device(s) in case of data gaps in main vector magnetometer, by simple substitution of "9s" in files in IMF or IAGA2002 formats by good values

Figure 5 show an example of data plots and difference plots of everyday processing, where the comparison of the horizontal component H of the main vector magnetometer FGE with data of the backup magnetometer GEM dIdD and Japanese fluxgate device FRG-601 is presented. This comparison is simple to achieve since the adopted baselines of all magnetometers were obtained on daily basis as close to "quasi-definitive" mode, without any delay. Similar plots are made for other components and for other devices. These differences allow detection of noise up to 0.1 nT against the background variations with range up to tens of nT. The magnetometers installed in different pavilions or at different pillars in the same pavilion function as gradiometers with the base ranging from meters to tens of meters.

(4) the maximal visualization of data should be provided at every step of the processing

The visual presentation of the results of the measurements and processing are powerful tools for the analysis of the large amount of data. By default, packages MATLAB and Octave offer graphical functions that provide for scaling, annotating, marking, returning coordinates, etc. and these are used in the developed software. The goals of graphical possibilities of the software are:

- the simplification of the perception of complex graphs (e.g., several curves in one panel)
- the indication (by color markers) of the poor data or

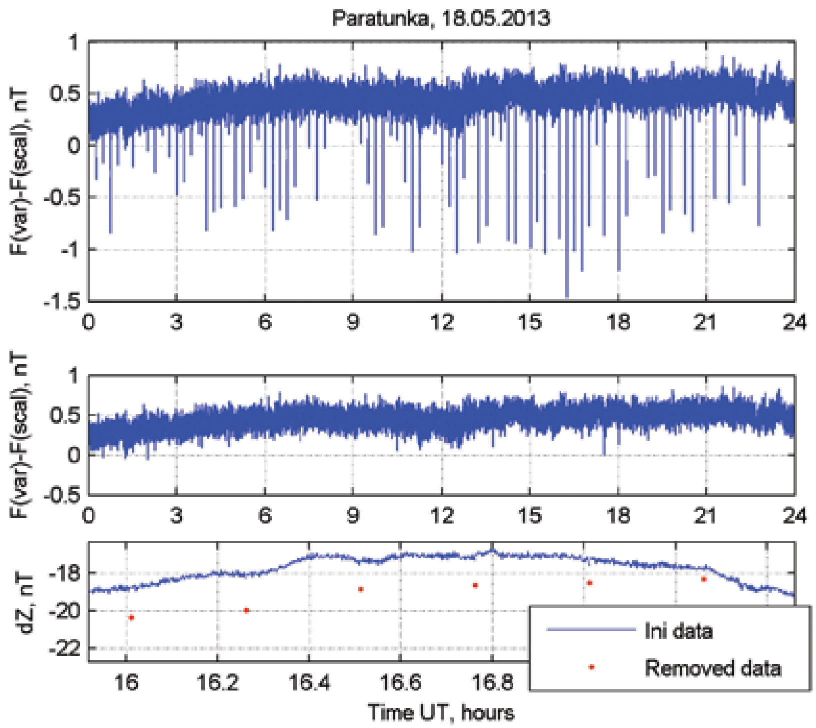

Figure 3. The example of the clearing of the noise in the magnetic data from the vertical sounding.

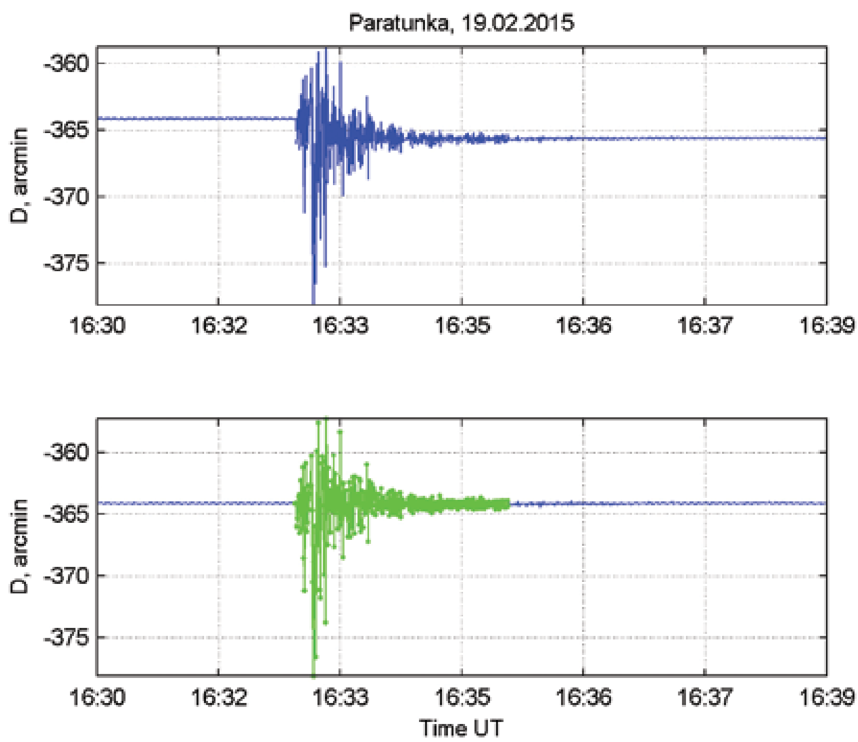

Figure 4. The example of the correction of the jump in the record level after strong earthquake. Upper panel – initial data with jump of -1.5' in D component, lower panel – after correction of jump and removing of earthquake effect (marked by dot).

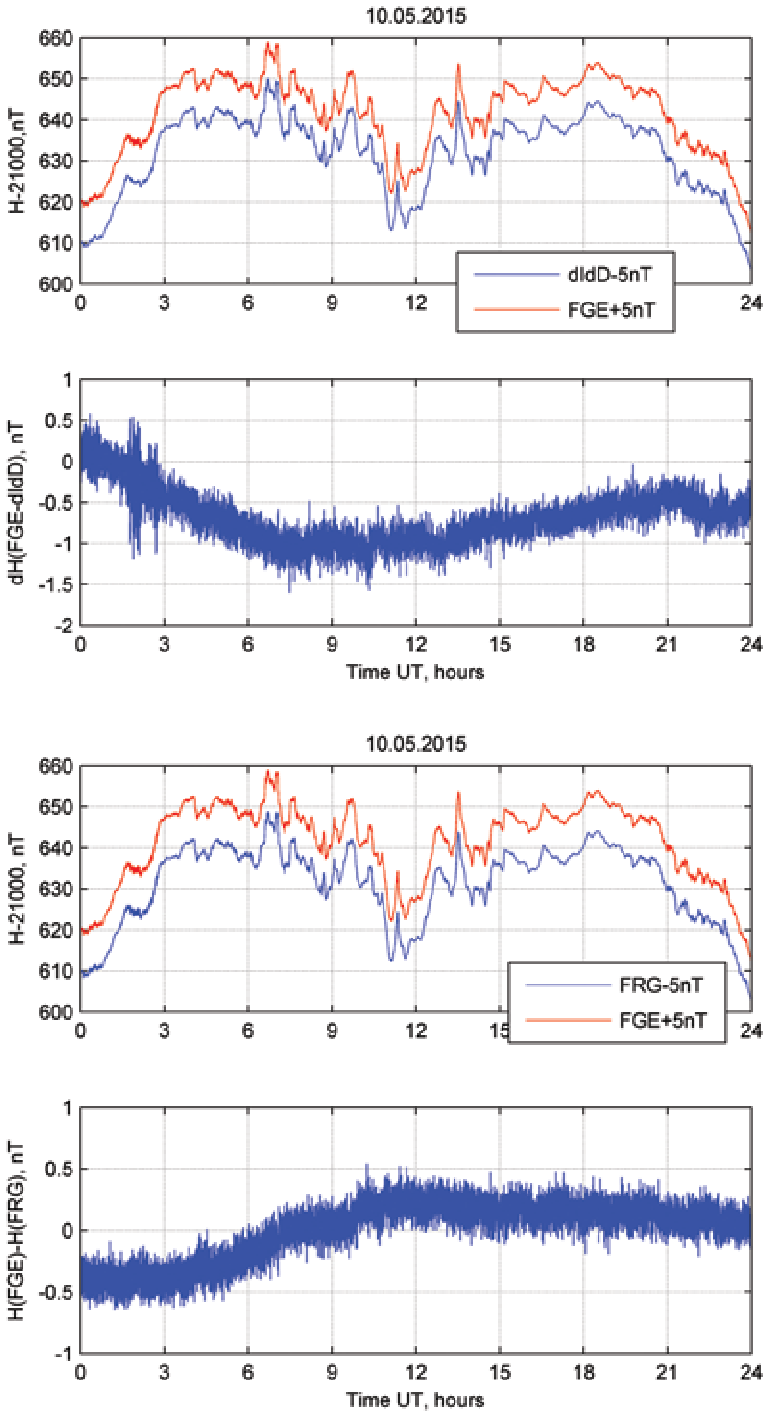

Figure 5. Comparison of the second values of the horizontal component H of the main vector magnetometer FGE (IMO PET) with data of GEM dIdD (two upper panels) and Japanese fluxgate variometer FRG-601 (two lower panels). Total values of H were calculated with "quasi-real" baselines.

deleted data

- re-scaling graphs to zoom in on details, which allows information to be interpreted directly from the curves

Figure 6 presents the graphs, which are plotted during the processing of the absolute observations. These plots make it simple for the magnetologist to compare observations with recorded field values, allowing them to evaluate the accuracy of the absolute observation form, typing data to file and to determine the behaviour of the field at these points of time (disturbances, noise etc.).

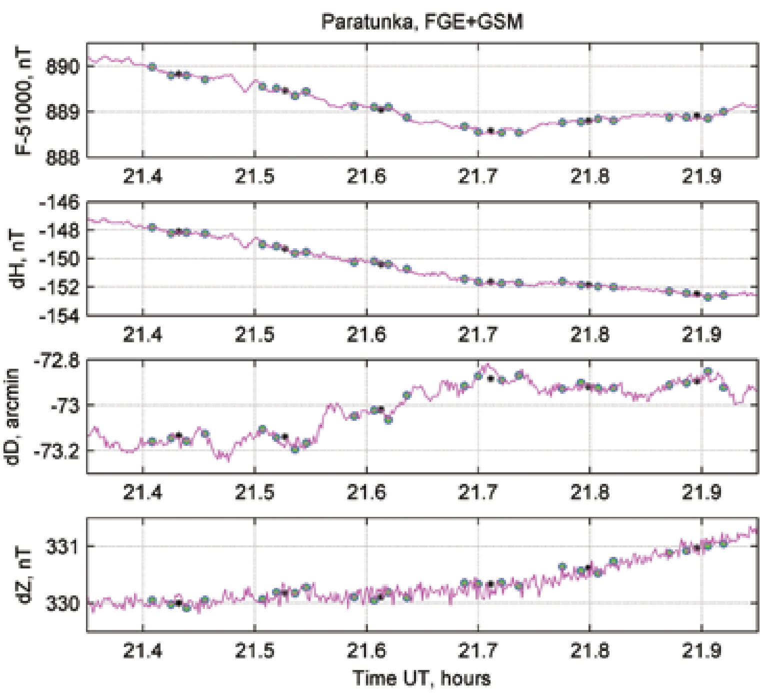

Figure 6. The plot of the data of the vector (dH, dD, dZ) and scalar (F) magnetometers during the processing of the results of the absolute observations. Solid curves are initial (second) data, circle markers indicate the values at time of "zero-position" of the DIflux during absolute observations and asterisk are the averages of the field values and time data.

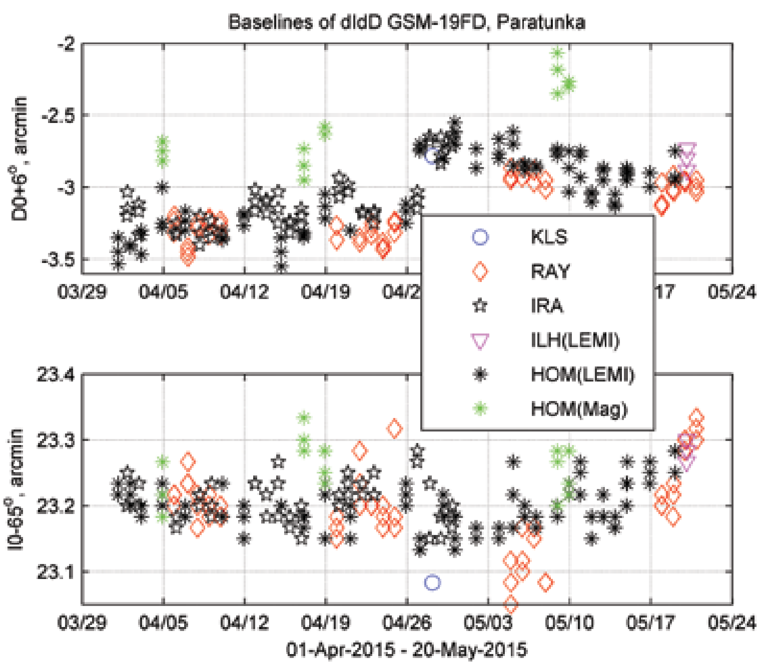

Figure 7. The example of the graphs of the baseline values for dIdD (IMO PET), which the observer can see after the processing of absolute observations.

Figure 7 presents the results of the absolute observations after processing of baselines as obtained from two DIflux (LEMI-203 and Mag-01H) by five observers, marked in different colors and symbols. Similar plots are generated directly after processing each absolute observation, such that the observer can estimate the quality of results and correct data or reject resulting baseline values.

Similar plots to those shown in Figures 2-5 are displayed at every step of processing, aimed at highlighting similarities and differences. For example, the showing of the variations dH,dD,dZ at separate panels allow easy scaling of every curve by amplitude. Presentation of three curves in single plot make it easy to select data fragments of interest by time. It is also important to note that all the principles presented above which are realized at magnetic observatories of IKIR FEB RAS primarily focused on the processing of the worst-case situations: crashes and hardware failure, noise, mistakes of magnetologist during manual work and so on. It is clear that under ordinary conditions all procedures can reliably operate in automatic mode.

CONCLUSIONS

Over the recent decades a lot of progress has been made in the standardisation of equipment and services for acquisition and publication of data in magnetic observatories around the world. However, there are problems with processing and the primary data analysis, the methods of which have been developed by observatories in their own traditions and do not conform to a uniform framework of Standard Operating Procedures (SOP). Availability of an efficient, comfortable and user oriented software for such processing for all the steps of data generation would make a huge difference to reporting of quality data to the global network.

The observatory of IKIR FEB RAS uses a new program to process magnetic data both for everyday reporting and for the preparation of quasi-definitive and definitive data. Software was developed under MATLAB and OCTAVE packages, have open source code and can be expanded and modified to specific instruments and possibilities of every observatories. The basis of the software incorporated several methodological principles generally oriented to work with the data by magnetologist directly at observatory, including under abnormal situations. Some part of software is also used at other INTERMAGNET observatories (Novosibirsk, Yakutsk, Alma-Ata).

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