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On the feasibility of routine baseline improvement in processing of geomagnetic observatory data

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Abstract

We propose a new approach to the calculation of regular baselines at magnetic observatories. The proposed approach is based on the simultaneous analysis of the irregular absolute observations and the continuous time-series deltaF, widely used for estimating the data quality. The systematic deltaF analysis allows to take into account all available information about the operation of observatory instruments (i.e., continuous records of the field variations and its modulus) in the intervals between the times of absolute observations, as compared to the traditional baseline calculation where only spot values are considered. To establish a connection with the observed spot baseline values, we introduce a function for approximate evaluation of the intermediate baseline values. An important feature of the algorithm is its quantitative estimation of the resulting data precision and thus determination of the problematic fragments in raw data. We analyze the robustness of the algorithm operation using synthetic data sets. We also compare baselines and definitive data derived by the proposed algorithm with those derived by the traditional approach using Saint Petersburg observatory data, recorded in 2015 and accepted by INTERMAGNET. It is shown that the proposed method allows to essentially improve the resulting data quality when baseline data are not good enough. The obtained results prove that the baseline variability in time might be quite rapid.

Keywords: Geomagnetism, Observatories, Instruments and techniques

Introduction

The Earth's magnetic field (EMF) is the one of the most important sources of information about the physical processes occurring inside the Earth and in the circumterrestrial space. The data on the magnetic field's state and its temporal variations are registered using modern magnetometers installed on special satellites and ground-based magnetic observatories. Despite the advantages of satellite measurements, there are a number of limitations that do not allow us to abandon the classical magnetic field measurements of stationary observatories. The measuring satellites are relatively recent and inevitably have a limited lifetime. The typical duration of the continuous satellite data time series does not exceed 10 years, whereas the oldest geomagnetic observatories provide continuous series of observations lasting more than a 100 years. Such records are of exceptional value for the fundamental researches in the field of geomagnetism assuming the study of the evolution of the Earth's magnetic field and the associated dynamic processes in the outer core over longtime intervals. The development of science in the study of the magnetic fields of the Earth and the Sun requires a permanent improvement of the quality of the data provided by the observatories as the adequacy of reproducing the characteristics of the magnetic field outside the points of actual measurements using appropriate mathematical models depends directly on it.

Over the past decades, the highest international standard for the quality of geomagnetic observations was elaborated within the framework of the INTERMAGNET program (Love and Chulliat 2013). To date, this standard

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excluded from consideration when evaluating the processing results.

Thus, the comparative analysis shows that the definitive data obtained using the developed algorithm meet the INTERMAGNET requirements. Moreover, due to the new method, the data quality indicators are essentially improved, comparing to the classical approach, and also a relevant estimation of the measurement quality during the analyzed time interval is provided. Taking this estimation into account, it becomes possible to set the minimal quality level required for the final data and, when processing the observations from several observatories, to rank the individual data fragments according to their quality.

Conclusions

The developed approach allows to build a baseline in a semiautomatic mode using all the available data from the observatory. They include not only the observed baseline values derived from spot values of the magnetic field components and its total intensity at the times of absolute observations, but also the continuous data of vector and scalar magnetometers. The latter are not used in traditional observatory practice when calculating the regular baselines. The developed approach is based on the minimization of the target functional ϕ, which is a linear combination of two functions G and A, connected with a weight factor λ. The G function is responsible for estimating the difference of the vector magnitudes obtained from the independent vector and scalar recordings, and the A function represents the conformity of the considered baseline vector to the observed ones at two nearest times. The resulting series of the found minima of the ϕ function (Q_ϕ) represents a quantitative estimation of confidence in the obtained baseline values for each time moment. The method is adopted for Cartesian component measurements of the magnetic field and will not work in its present form for dIdD or LAMA variometers as they record spherical components.

It should be noted that the traditional approach to quasi-definitive (Peltier and Chulliat 2010) and definitive data preparation involves the interpolation of the observed baseline values. With that, the interpolation parameters are defined individually for each observatory and depend on the instrumentation used, the measurement quality, the typical baseline value dispersion, etc. In the proposed method, the free parameter λ has a clearer physical meaning, and its selection is less subjective. Moreover, the selection of the parameter can be automated, for example, by the analysis of statistical features of the initial data. An important feature of the algorithm is the possibility of a quantitative estimation of the resulting data precision and, thus, determination of the problematic fragments in initial data without operator intervention.

The algorithm operation was evaluated both on synthetic examples and on real data registered in 2015 at the Saint Petersburg INTERMAGNET observatory. The data obtained using the proposed method were compared with the definitive data officially accepted by INTERMAGNET. The advantages of the new method are demonstrated, and it is shown that it allows to essentially improve the resulting data quality as compared to the classical approach. The obtained results prove that the baseline variability in time should not necessarily be smooth. In particular, this may be due to the distance between the variation and absolute pavilions: the more this distance, the less smooth is the baseline (Lesur et al. 2017). At the same time, the assumption of the baseline smoothness might lead to the loss of the information about the geomagnetic signals of small spatial scale (100–200 m) but quite lasting (~ 1 day long), with the amplitude of several nanoteslas. In turn, this will add significant distortion into the models of rapid core field variations built using observatory data.

Abbreviation
EMF: Earth's magnetic field.

Authors' contributions
AS performed the resulting analysis and drafted the manuscript. VL set the problem and advised for data interpretation. DK developed software and carried out data processing. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
INTERMAGNET data and Russian observatory data are available from http://www.intermagnet.org and http://geomag.gcras.ru.

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