AN INSTRUMENT PERFORMANCE AND DATA QUALITY STANDARD FOR INTERMAGNET ONE-SECOND DATA EXCHANGE

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SUMMARY

With the advent of developments in instrumentation, data acquisition and data dissemination, an increasing number of observatories are producing a filtered one-second data product in addition to traditional one-minute data, hourly means, daily means, monthly means and annual means. An INTERMAGNET survey of the user community in 2005 concluded that there is a desire for one-second data to be made available through the INTERMAGNET network and that, as is the case for one-minute data, a minimum standard of instrument performance and data quality should be set for definitive one-second data. Here, the INTERMAGNET Observatories & Standards Subcommittee introduces such a one-second data standard resulting from consultation with the scientific community and instrument developers.

1. INTRODUCTION

INTERMAGNET is a global network of over 100 absolute geomagnetic observatories formed as cooperation between international geophysical institutes. Since its inception in 1991, INTERMAGNET has made use of existing technologies to disseminate data from observatories in the network to data users in near real-time and to provide a publishing platform for final (or definitive) data sets. To ensure operational uniformity and to provide a consistent data quality across the network, the INTERMAGNET Operations Committee publishes a set of common standards (INTERMAGNET, 2011), which include definitions of file formats for data exchange as well as parameters detailing the minimum quality requirements for an observatory participating in the network.

Since 1991, the principle INTERMAGNET publication output has been an annual definitive data set comprising one-minute, three-component samples from each of the participating observatories, along with associated metadata and derived mean values. Recent developments in technology have now made it possible to manipulate and exchange data at a higher sample rate and several INTERMAGNET observatories have begun to make experimental one-second recordings, enabling monitoring of a higher frequency band of the geomagnetic spectrum. As a result of the requirements of the observatory and scientific communities, manufacturers have also begun to develop instruments capable of sampling at this higher data rate.

Based on a survey of the geomagnetic scientific community, and in consultation with observatory operators and instrument producers, INTERMAGNET has drafted a set of data quality standards intended to apply to future publication of definitive one-second data. Rather than set out the specifications of the instrument alone, the parameters described here define the overall specifications of a complete observatory system for a one-second vector data set including recording environment, magnetometer, and data processing procedure. The standard has been defined such that the general parameters of the system transfer function are specified. However, to allow a range of instrumentation and system solutions, specific parameters such as base sampling frequency and digital filter type are not explicitly defined.

2. INTERMAGNET ONE-SECOND DEFINITIVE DATA SPECIFICATIONS

The consensus of a survey of the scientific community conducted by INTERMAGNET was that, in order to ensure that one-second data acquired by the INTERMAGNET network was of sufficient quality, the minimum parameters should be: accurate time stamping (within 0.01 s); high resolution (<0.01 nT); uniformly & digitally filtered with near linear phase response. The task of the INTERMAGNET

Observatories & Standards Subcommittee has been to interpret these general requirements set by the user community into a practical data standard of use to the observatory community. The resulting specification parameters are listed in Table 1.

Table 1 – INTERMAGNET One-second Definitive Data Specifications

General Specifications	
Time-stamp accuracy	0.01 s
Phase response	±0.01 s
Maximum filter width	25 seconds
Instrument Amplitude Range	≥±4000 nT High Latitude, ≥±3000 nT Mid/Equatorial Latitude
Data resolution	1 pT
Pass band	DC to 0.2 Hz
Maximum component orthogonality error	2 mrad
Maximum Z-component verticality error	2 mrad
Pass Band Specifications [DC to 8 mHz (120 s)]	
Noise level	≤100 pT RMS
Maximum offset error	±2. 5 nT
Maximum component scaling & linearity error	0.25%
Pass Band Specifications [8 mHz (120 s) to 0.2 Hz]	
Noise level	≤10 pT/√Hz at 0.1 Hz
Maximum gain/attenuation	3 dB
Stop Band Specifications [≥ 0.5 Hz]	
Minimum attenuation in the stop band (≥ 0.5Hz)	50 dB
Auxiliary measurements:	
Compulsory full-scale scalar magnetometer measurements with a data resolution of 0.01 nT at a minimum sample period of 30 seconds. Compulsory vector magnetometer temperature measurements with a resolution of 0.1 °C at a minimum sample period of one minute.	

3. GENERAL SPECIFICATIONS

To comply with the requirements stipulated by the user community, the standards set in Table 1 specify a maximum time-stamp error for data digitally filtered to one-second samples. The time-stamp error applies to the centre point of the digital filter and is measured from the top of the UT second.

To meet the requirement for linear phase, a maximum group delay (frequency derivative of phase) is set as a limit on non-linearity. Data samples may be time-shifted to correct for latency (e.g. instrument response and filter delay) provided that the system phase response is met.

The specified minimum instrument ranges have been inherited from the INTERMAGNET one-minute specification to provide an attainable noise level for an instrument of fixed dynamic range, however it is recognised that these ranges may be exceeded by extreme geomagnetic events hence it is recommended that either a low-gain instrument is run in parallel; an offset is applied to the H-component; or the instrument range is extended (e.g. by auto-ranging).

A maximum filter width is set to minimise the time extent of the system response to a step input i.e. filter ringing.

4. PASS BAND SPECIFICATIONS [DC TO 8 mHz (120 s)]

Observatories moving from absolute one-minute recordings to absolute one-second recordings will require to monitor over not only a larger frequency band but, due to the spectrum of the natural magnetic field, also a larger dynamic range. To meet these stringent measurement requirements yet ensure that the limitations on the instrumentation are realistic, the pass band has been split into two: the existing INTERMAGNET one-minute data band (DC to 120s) and the extended band (8mHz to 0.2Hz).

In comparison with the extended band, the low frequency band (DC to 120s) has been specified a higher system noise level limit but more constraint on the absolute accuracy. The offset error specifies a maximum low frequency instrumental error, including instrument drift and thermal drift i.e. an absolute accuracy limit. Here, there is no specification on the frequency of absolute magnetic observations, other than observations must be sufficient to achieve the specified maximum offset error under quiet geomagnetic conditions.

It is recognised that in setting a scaling & linearity limit of 0.25%, this creates an inconsistency with the maximum offset error for variations in the magnetic field over 1000nT. Such large disturbances are considered to be of sufficiently short duration and scarcity that it is reasonable to specify errors during these periods in terms of percentage accuracy at the expense of absolute accuracy. In other words, the scaling & linearity error could be considered to apply to the higher frequencies (within the DC to 0.2Hz band) and the maximum offset error to the lower frequencies without explicitly specifying a delineating frequency. The inconsistency between the two standards is deemed necessary in order to specify an achievable system calibration parameter, whilst also specifying an absolute accuracy level that applies during normal conditions i.e. where the field deviates by no more than 1000nT from quiet level between absolute observations, which is the significant proportion of the time series.

5. PASS BAND SPECIFICATIONS [8 mHz (120 s) to 0.2 Hz]

In the high frequency band of the pass band (8 mHz to 0.2 Hz), the noise level is set at a lower level to ensure sufficient resolution of low amplitude signal in this band of the natural geomagnetic spectrum. Since absolute signal amplitude is not as critical to the user community in this band as it is in the low frequency band, and to allow for instrument roll-off with sufficient attenuation in the stop band, the maximum signal gain/attenuation is specified at a less stringent 3dB in the high frequency band.

6. STOP BAND SPECIFICATIONS [≥ 0.5 Hz]

The minimum stop band attenuation parameter has been set to ensure an easily achievable roll-off in the transition band whilst reducing aliased natural geomagnetic signal in the pass band to below the specified pass-band noise levels. However, there remains the possibility that large amplitude, non-natural signals in the stop band (e.g. 50/60 Hz) could be aliased into the pass-band at frequencies other than 0.1Hz and still meet this specification, hence there is a recommendation to separately attenuate (e.g. by a notch filter) non-natural, large-amplitude signals above the Nyquist.

7. AUXILLIARY MEASUREMENTS

Another modification over the INTERMAGNET specification for one-minute data is the requirement for auxiliary measurements from an absolute scalar magnetometer and monitoring of the variometer temperature for the purpose of quality control.

8. CONCLUSIONS

The authors acknowledge that the instrument specifications, particularly the low noise level in the pass band, are not met by most of the instrumentation currently available. However, the authors have undertaken extensive consultation with instrument manufacturers to ensure that these specifications are realistic and can be achieved by manufacturers in further developments of their instruments. It is also necessary to set such ambitious specifications to ensure that future observatory data sets are well suited to the needs of the data user community.

The set of standards described here will be defined and, where possible, tested to be the minimum quality requirements for definitive one-second data to be distributed by absolute magnetic observatories via the INTERMAGNET web site and DVD. For the purpose of brevity, a full discussion on the proposed standard has not been included here, but has been documented in INTERMAGNET Discussion Document 20, a copy of which can be obtained from a member of the Observatories & Standards Subcommittee or by request from secretary@intermagnet.org.

It is important to note that, whilst INTERMAGNET encourages observatories to participate in the exchange of one-second data, the INTERMAGNET network will continue to distribute one-minute data and existing definitive one-minute standards are unaffected.

9. ACKNOWLEDGEMENTS

In reaching the set of standards listed here, the INTERMAGNET Operations Committee has sought consultation with as broad a representation of the data user community, observatory operators and instrument developers as possible. In particular, the Operations Committee is grateful to the following for their valuable input in this process: Arnaud Chulliat, Laszlo Hegymegi, Valery Korepanov, Xavier Lalanne, Andriy Marusenkov, Barry Narod, Lars William Pedersen, Jan Raagaard Petersen, Gerhard Schwarz and Tom Shanahan.

10. REFERENCES

INTERMAGNET Operations Committee. (2011): "INTERMAGNET Technical Reference Manual V4.5".*c/o Natural Resources Canada, #7 Observatory Crescent, Ottawa, Ontario Canada K1A 0Y3*.