Analysis of USGS One-Second Data

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One-second fluxgate magnetometer data are now being collected at most U. S. Geological Survey (USGS) geomagnetic observatories. As part of a process of validation, it is necessary to determine the resolution and noise content of the new data. Two different analysis methods are used in this study. The first method consists of analysis of second-to-second differences (first differences) in the data collected from a given magnetometer. The root mean square (RMS) of the differences is calculated for short running durations over the course of a day. The second method consists of side-by-side comparisons of data at observatories where two magnetometers are operated in parallel. Here, again, a running RMS of the difference is calculated over the course of a day. Results show that most of the data have a resolution of 0.01 to 0.02 nT.

Introduction

For the past 30 to 40 years geomagnetic observatory data have been reported as one-minute values. These data have been of great use to the scientific community, especially in the field of space physics. More recently, however, some of the focus of research has shifted towards the analysis of data with a higher time resolution. These data have mostly been obtained by magnetometer networks deployed during temporary campaigns pursued by academic scientists at universities or research consortiums. With the exception of a few observatories, such as Kakioka, Japan, most of the global observatory community has only begun to focus on the routine and long-term acquisition of one-second data. A survey of the space physics community, done for Intermagnet (Love, 2005), demonstrated a need for one-second data having a resolution of about 0.01 nT and a timing accuracy of about 0.01 seconds.

This paper examines one-second data collected at USGS observatories where a new one-second acquisition system is used. Our analysis of the one-second data evaluates the resolution and noise level at the observatories where the data is being recorded.

Data Description

To better meet the needs of the space physics community, the USGS developed and deployed a new data acquisition system capable of recording one-second data. In order to obtain a combination of time-stamp accuracy and resolution, the Narod ring-core fluxgate magnetometer analog output is oversampled at 100 Hz. The analog outputs are passed through an anti-aliasing three-pole Butterworth filter having a corner frequency of 50 Hz. This introduces only very minor frequency-dependent-phase distortion to the signal and allows for the assignment of a time stamp with about 0.01 seconds accuracy. These samples are then digitized using an Ethernet-based, 24-bit A/D converter and passed through a Gaussian digital filter having a width of about two seconds. The result is a one-second average datum. One-second values are obtained for all three components of the magnetic field and are stored on an on-site computer.

This acquisition system has been deployed at 13 of the 14 USGS magnetic observatories with two at Boulder Observatory (BOU). At the College Observatory (CMO), the USGS system operates in parallel with a one-second system operated by another agency. This permits two different techniques for examining the noise and resolution of the USGS one-second data.

Noise Analysis

At observatories where there is a single fluxgate magnetometer in operation we examine the first difference to determine the root-mean-square (RMS) error. As a first step, the data for each component is plotted to check the integrity of the data. We want to make sure that there are no external spikes, offsets, or artificial disturbances in the data. The first difference (δH) or second-to-second difference is computed between successive data points, of an individual component, over an entire day,

$\delta H(t_i) = H(t_i) - H(t_{i+1})$, for i = 1 to 86399.

The mean and standard deviation of the first difference are computed over successive five minute intervals (600 points) throughout the day to determine the RMS error as a function of time of day (figure 1).

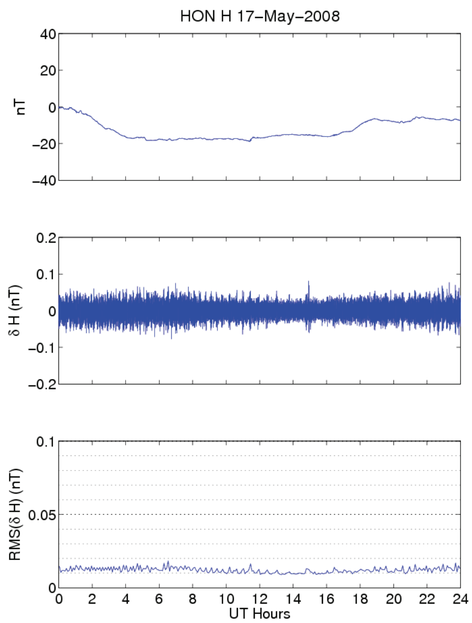

Figure 1. Results of a first difference calculation for the H component from Honolulu for May 17, 2008. This shows the raw data (top), the first difference (middle), and the RMS error of the first difference δH (bottom) as a function of time of day. In this example the noise level is about 0.01 nT at its lowest value.

At observatories with two one-second magnetometer acquisition systems in operation we can use a different technique to analyze the noise. At Boulder Observatory we have the primary system plus an identical secondary system operating on-site. At College Observatory there is an acquisition system operated by another agency that collects one-second fluxgate data of similar resolution.

The data from the two systems are first checked for spikes, offsets, and artificial disturbances and to make sure the two data sets coincide over the same time interval. We then compute the differences between each fluxgate component from the two systems,

$\Delta H(t_i) = H_1(t_i) - H_2(t_i)$, for i = 1 to 86400.

The standard deviation of these differences is computed to obtain an estimate of the RMS error for each component. Similar to the single magnetometer technique, we computed the RMS error over successive two minute (120 point) windows for the entire day (figure 2).

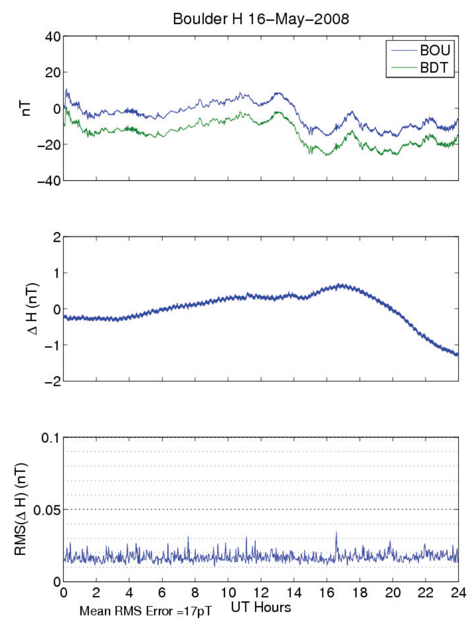

Figure 2. This example shows data from the two data collection systems at Boulder, CO for May 16, 2008. This shows the H component for Boulder (BOU) and the Boulder Secondary system (BDT) (top), the difference between the two systems, ΔH (middle), and the RMS error of ΔH computed over two-minute intervals (bottom).

This analysis technique has the advantage that the regular variations of the magnetic field are removed and will not affect the results. What remains is the combination of the system noise of both data acquisition systems.

Discussion

Results using the single magnetometer analysis technique show that most of the USGS observatories have noise levels of about 0.01 nT RMS (table 1). We performed the analysis using several quiet days of data at each observatory to obtain an average value for the horizontal (H) component. The results for the D and Z components were similar to the H component. The first difference technique fails when the field is rapidly changing, with large amplitude changes. Large amplitude field changes, because of increased magnetic activity, obscure the amplitude of the magnetometer noise.

Table 1. Noise test results for the H component for the USGS observatories

Obsy	RMS Noise (nT)	
	Single Mag.	Two Mags.
BOU	0.010	0.017
BDT	.012	
BSL	.009	
BRW	.010	
CMO	.012	.023
FRD	.018	
FRN	.019	
GUA	.014	
HON	.011	
NEW	.011	
SHU	.013	
SIT	.022	
SJG	.015	
TUC	.012	

The dual magnetometer analysis gives RMS noise levels that are larger than the single magnetometer technique. These RMS noise results contain the noise from both recording systems. In each case we first used the single magnetometer analysis technique to look at the noise from each individual system. The RMS noise level measured between the two systems should be the square root of the sum of the squares of the noise level from each individual system,

$$N_{1\text{-}2} = (N_1^2 + N_2^2)^{1/2}.$$

Comparisons of data at Boulder are relatively easy to compare because the two systems are identical. The results from the comparison of the H components at Boulder give good results (figure 2). The RMS noise level between the two systems gave a result of 0.017 nT. Analysis of the two systems at Boulder using the single magnetometer technique resulted in noise levels of 0.010 RMS and 0.012 nT RMS (figures 3 and 4). The combination of these two noise levels results in 0.016 nT which matches well with the dual magnetometer technique.

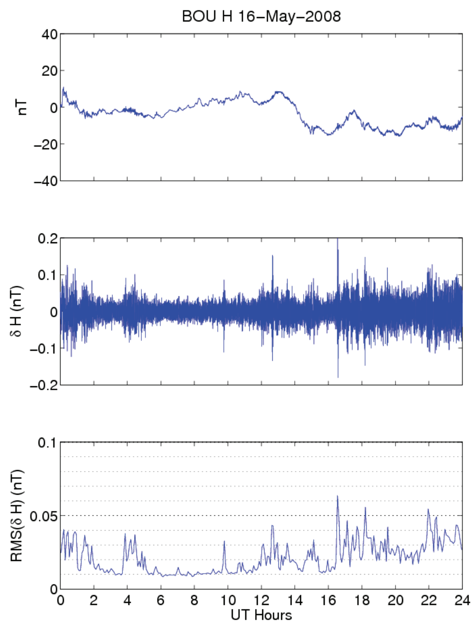

Figure 3. Results of a first difference calculation for the H component from Boulder for May 16, 2008. This shows the raw data (top), the first difference (middle), and the RMS error of the first difference δH (bottom) as a function of time of day. In this example the noise level is about 0.010 nT at its lowest value.

The comparison at College Observatory (CMO) requires more care. The second system at College Observatory is operated by the University of Alaska Fairbanks, Geophysical Institute (GI). They use the same fluxgate magnetometer that the USGS uses, but their data recording system is different than the USGS system. The GI samples the analog output of the magnetometer at 8 Hz and uses a boxcar average to determine an average one-second datum. The boxcar average is not centered on the minute. We applied a 1 to 300 mHz band-pass filter to both data sets to compensate for different filter settings and acquisition parameters between the two data recording systems.

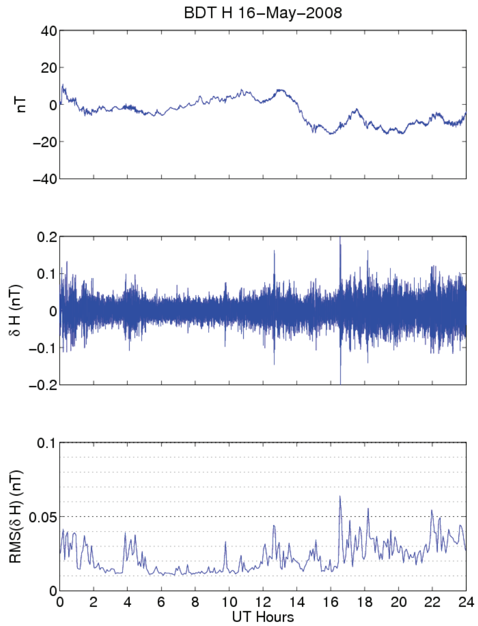

Figure 4. Results of a first difference calculation for the H component from Boulder secondary system (BDT) for May 16, 2008. This shows the raw data (top), the first difference (middle), and the RMS error of the first difference δH (bottom) as a function of time of day. In this example the noise level is about 0.012 nT at its lowest value.

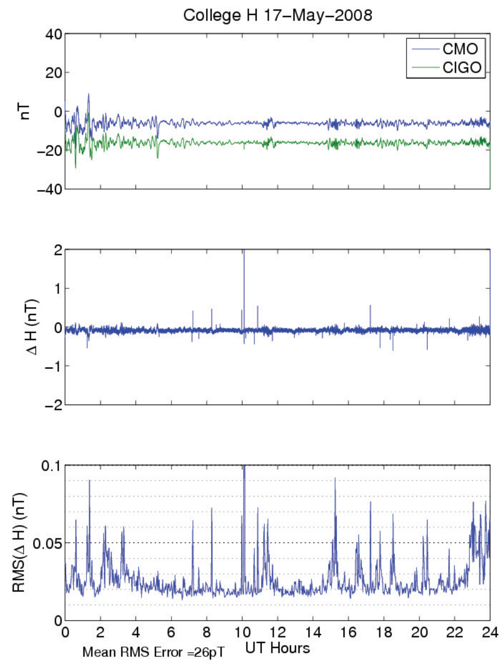

Figure 5. This example shows data from the two systems at College, AK for May 17, 2008. This shows the H component for USGS College magnetometer (CMO) and the UAF-GI College magnetometer (CIGO) (top), the difference between the two systems, ΔH (middle), and the RMS error of ΔF computed over two-minute intervals (bottom).

The comparison at College Observatory, for the H component, produced a noise level of 0.026 nT after accounting for a one-second time difference between the two data sets (figure 5). The random spikes seen in the H difference are of unknown origin. Analysis of each individual system shows that the USGS data has a lower RMS noise level than the GI system, 0.012 nT and 0.021 nT respectively.

Conclusion

The two analysis techniques were successful in estimating the noise levels of our one-second data. The single magnetometer analysis works well when the magnetic field is in a quiet, undisturbed condition. When the magnetic field is in a disturbed condition, this technique breaks down. At all but two of our sites, this is the only analysis technique presently available because there is a single magnetometer in operation.

There was a concern that the RMS error determined from this analysis method might be latitude-dependent. We plotted the RMS error for each observatory in a stack plot as a function of latitude (figure 6). In looking at the noise levels we see that the results have little variation with latitude. At the two high latitude observatories, College and Barrow (BRW), the noise level is on the order of 0.01 nT which is very similar to the noise level at most of the other observatories. The difference is that the field is more active at the higher latitudes but when the field is in a quiet state the first difference technique can produce satisfactory noise level determinations.

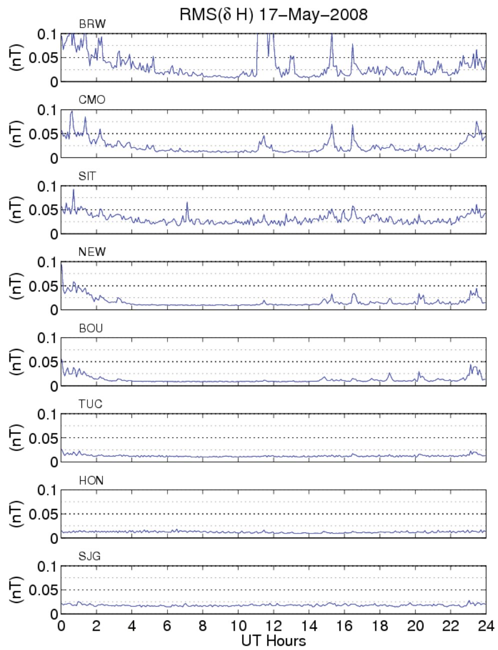

Figure 6. A stack plot of the RMS error of the H component for eight USGS observatories on May 17, 2008. The graphs are arranged from high magnetic latitude at the top to low latitude at the bottom.

The dual magnetometer technique is successful when comparing data from identical systems. It is probably a better measure of the noise level because it removes magnetic field variations from the analysis. When comparing data from different acquisition systems the technique is not as useful because of differences between the acquisition systems and magnetometers.

The RMS noise levels from all of the reported observatories are on the order of 0.02 nT or less (Table 1). About half of the observatories have noise levels of about 0.01 nT.

Acknowledgements
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References

Love, J. J., 2005, 1-Second Operational Standard for INTERMAGNET, *Minutes of the OPSCOM/EXCOM MEETING, Mexico 2005*.