Total Field Sensor Comparison

Timothy C. White

U.S. Geological Survey

geomag.usgs.gov

Introduction

During the XIIIth IAGA Workshop (hereafter referred to as "the workshop"), several total field comparison measurements were conducted at the Boulder Magnetic Observatory (BOU). The purpose of these tests was to look for errors within the total field instruments which are considered "absolutes" instruments. The total field measurement is a critical component of the absolute measurement computation. Samples between two total field sensors, corresponding in time, were directly compared. Other methods for calibration exist for these sensors, including the use of frequency generators (Jankowski and Sucksdorff, 1996). This test was not utilized at this workshop.

Method

The participants were David Kalp of Canada, Hans-Joachim Linthe of Germany, Santiago Marsal of Spain, Kari Pajunpaa of Finland, and Tim White of the United States. The instruments used were primarily Gem Systems Overhausers (GSM-19). Kari Pajunpaa's instrument was a Russian Proton magnetometer (PMP-7), and was manually sampled approximately every 10 seconds. David Kalp's and Tim White's instruments were tested after the workshop because of logistical issues. All tests were performed in July and August 2008. These test systems were compared against the U.S. Geological Survey BOU Gem Systems GSM-19 Overhauser. Table 1 summarizes the testing specifications for each participant's system.

TABLE 1. Instrument and testing specifications.

Participants	Instrument make/model	Date of test	Start time (UTC)	Duration of test (s)	Sampling rate $(\frac{\text{Samples}}{\text{Second}})$	Number of samples
David Kalp, Canada	Gem Systems, GSM-19	July 10, 2008	14:25:11	17,788	1	17,788
Kari Pajunpaa, Finland	PMP-7	June 11, 2008	12:57:50	480	$\frac{1}{10}$	48
Hans-Joachim Linthe, Germany	Gem Systems, GSM-19	June 11, 2008	13:51:56	36,141	$\frac{1}{3}$	12,046
Santiago Marsal, Spain	Gem Systems, GSM-19	June 12, 2008	12:45:37	40,460	$\frac{1}{5}$	8,091
Tim White, United States	Gem Systems, GSM-19	August 15, 2008	00:00:00	86,400	1	86,400

The BOU system that was used in the comparisons as a baseline utilizes a Gem System GSM-19 Overhauser and is located in an enclosure 25 meters from the Variations Building, on a mechanically stable pier. There is no temperature control for the sensor enclosure. Ten meters of the sensor cable are located within an underground conduit. The other 15 meters of the sensor cable are located within the Variations Building mounted on the wall. The Variations Building has electric heaters to control the temperature. The thermostat within this building is set to maintain a temperature of approximately 23 °C. Given the high summer temperatures, it is unlikely that the heaters were used during the testing. The BOU Overhauser is sampled every second, pulse per second (PPS) triggered, and the resulting data was UTC (coordinated universal time) time stamped.

The participant's test systems were located at the Coil Calibration facility. The Coil Calibration Facility Buildings are located about 450 meters from the BOU system, see figure 1. The test sensors were located on a mechanically stable pier within the Coil Building. The electronics for the test systems were located in the Coil Control Building, with the exception of Kari Pajunpaa 's system, which was located entirely within the Coil Building. The Coil Control Building is located ~23 meters north of the Coil Building. The Coil Building had some temperature control, but the thermostat for the heating and cooling system was located within the Control Building and air was ducted from the Control Building to the Coil Building. All test sensors were placed in the same physical location (±5 cm). Sampling on the GSM-19-test systems was computer triggered but had varying sampling frequencies, see table 1. Kari Pajunpaa 's PMP-7 was manually triggered every 10 seconds.

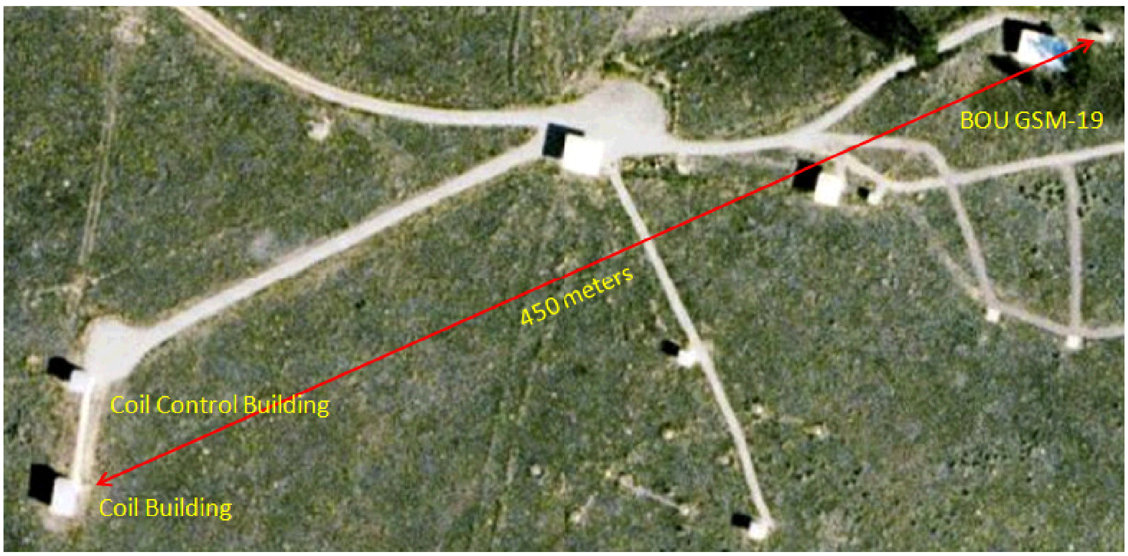

Figure 1: Aerial view of Boulder Magnetic Observatory.

Data collected by the test systems were directly compared to the corresponding samples collected by the BOU system. The test systems and BOU system were never accurately time synchronized; therefore, the data streams were shifted about the time axis to minimize the time synchronization error. Equation 1 models the analysis that was conducted.

$$\Delta \mathrm{F}(t_i) = F_{\mathrm{bou}}(t_{i+\delta}) - F_{\mathrm{test}}(t_i) \tag{1}$$

F_{bou} is the total field measurement from the BOU system. δ is the time offset required to sync the BOU system and the test system. Note that each data set from the different test systems has different values for δ. F_{test} is the total field measurement from the test system. The pier difference (ΔF) was plotted and averaged for each system, see Data section.

Data

On initial analysis of the data, several disturbances were noticed. The disturbance levels were -0.1 nT, and lasted about 5-15 minutes. The disturbances were not periodic and had not been observed during magnetometer calibration in the past. It is believed that the cycling of the heating and air conditioning unit, located at the Coil Control Building, was the source of the disturbances. A 200-point moving average filter was applied to the test data sets to eliminate the contaminated data before plotting. Figures 2-6 correspond to the pier difference measurement, in nT, as a function of sample number for each of the five test systems after the averaging filter was applied. A “zoomed” in view of the data also is presented for the GSM-19 test systems to present the sample-to-sample chatter characteristic of the test system. For simplicity, only 12,000 data points were displayed for David Kalp’s and Tim White’s test systems. The plots display a slight drift for all GSM-19 sensors. It should be noted that Santiago Marsal’s system displays a drift characteristic unlike the other GSM-19 test systems. The drift will be discussed in more detail later. Table 2 presents the mean values and standard deviations for each system.

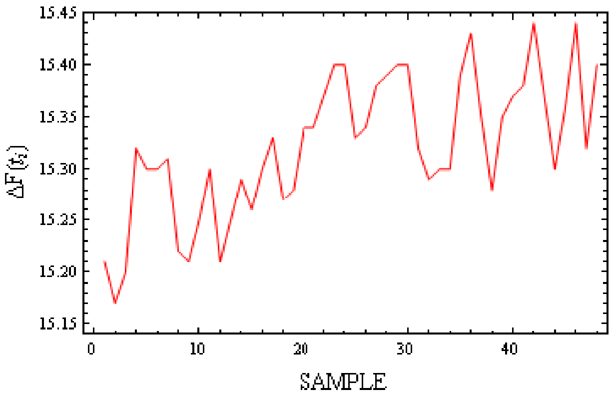

Figure 2: All pier difference results for Kari Pajunpaa’s test sensor.

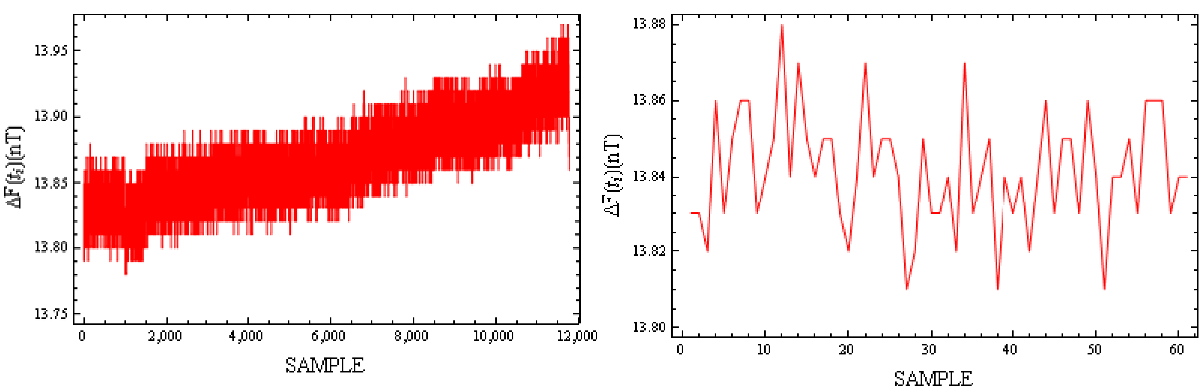

Figure 3: Pier difference results for David Kalp’s test sensor, left: first 12,000 filtered samples, right: 60 samples of data from start of test.

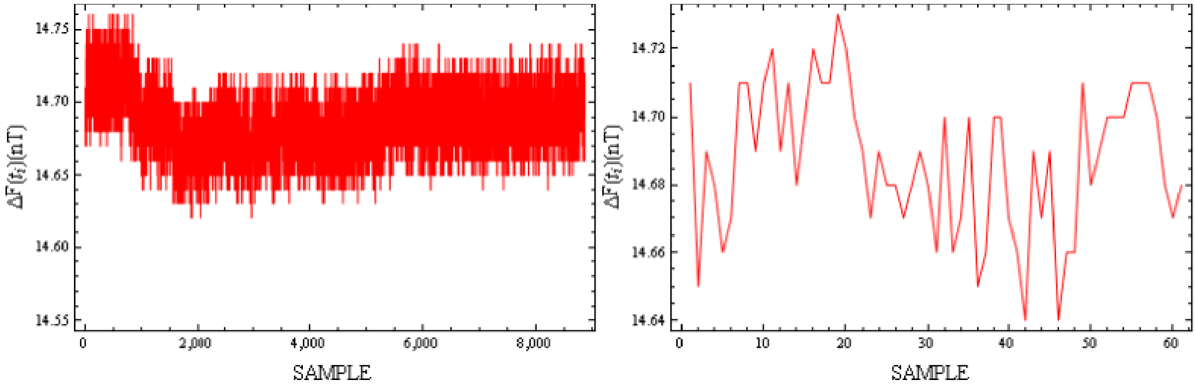

Figure 4: Pier difference results for Hans-Joachim Linthe's test sensor, left: filtered samples, right: 60 samples of data from start of test.

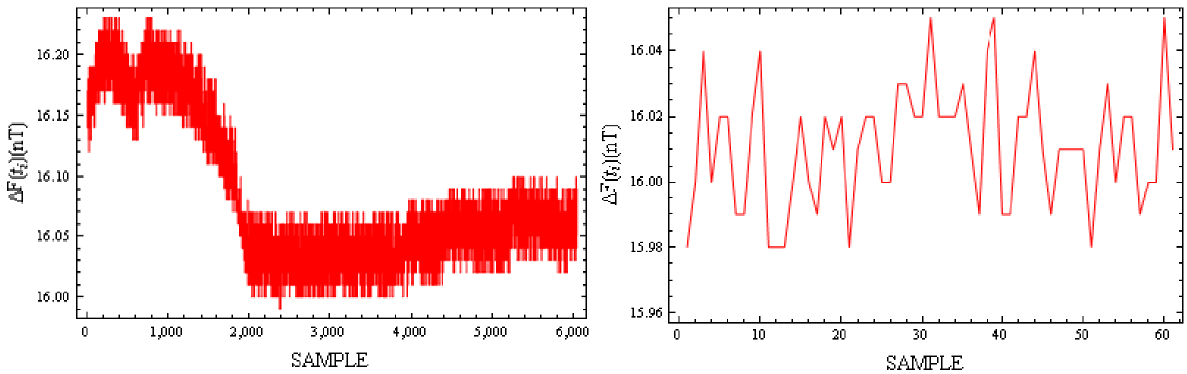

Figure 5: Pier difference results for Santiago Marsal's test sensor, left: filtered samples, right: 60 samples of data from start of test.

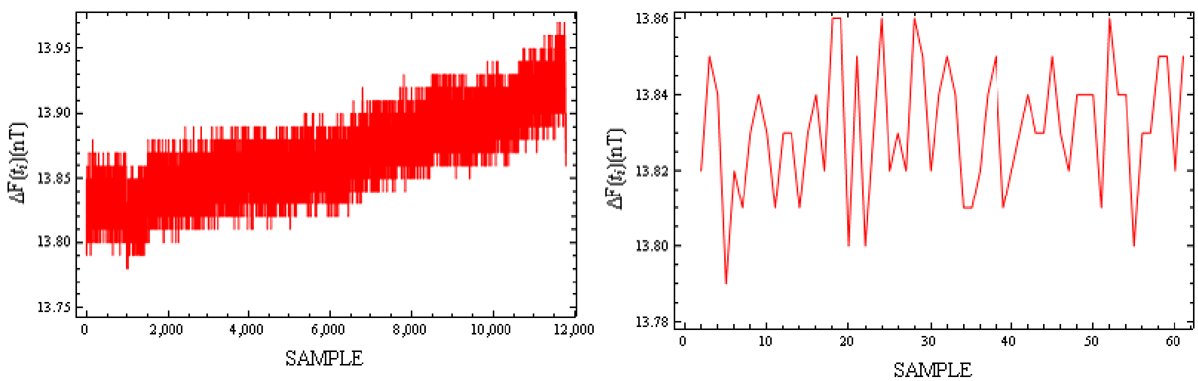

Figure 6: Pier difference results for Tim White's test sensor, left: first 12,000 filtered samples, right: 60 samples of data from start of test.

TABLE 2. Pier difference (ΔF) results.

Participants	Mean ΔF	Standard Deviation ΔF
David Kalp	13.87 nT	.032 nT
Kari Pajunpaa	15.32 nT	.067 nT
Hans – Joachim Linthe	14.69 nT	.024 nT
Santiago Marsal	16.06 nT	.062 nT
Tim White	13.58 nT	.020 nT
Range in ΔF	2.48 nT	

Observations

The total field measurements during the workshop revealed a 2.5 nT variation between the maximum ΔF and the minimum ΔF. Similar measurements were conducted to establish the ΔF for the absolutes piers used during the workshop. These measurements were conducted over three months in 2006, using seven different GSM-19 sensor systems. The mean variation of those measurements was 1-2 nT, which is slightly lower than the 2.5 nT measured for this comparative test. A gradient survey was conducted at the testing location using a GSM-19 gradiometer. The vertical gradients about the sensor location were small, 1.16 $\frac{\text{nT}}{\text{meter}}$. However, the horizontal gradients were very high, as much as 19.8 $\frac{\text{nT}}{\text{meter}}$. This high gradient helps explain the differences observed during the workshop testing as the sensors were only roughly placed in the same location (±5 cm). Equation 2 relates the positional error to our ΔF measurement error using the gradient measurements and the worst possible scenario for sensor placement. This calculation helps explain the observed ΔF spread for this test.

$$\Delta F_{error} = 0.10\,\text{meter} * 19.8\,\frac{\text{nT}}{\text{meter}} = 1.98\,\text{nT} \quad (2)$$

At present, the source of the drift observed by the GSM-19 instruments is unknown, but is being explored in collaboration with Gem Systems. It should be noted that the stated absolute accuracy of the GSM-19 is ±0.1 nT[2]. The internal heating of the sensor components and electric console components are suspected. Santiago's instrument is older than the rest of the test instruments and is suspected to have some electrical components that have a higher temperature coefficient. This in turn is the suspected cause of the unique drift characteristic displayed by his system.

Conclusions

Collecting a longer time series of data was very beneficial for this comparative measurement. The results that were attained had a large spread because of the high gradients but remain useful and will help improve the quality of observatory data. The test also identifies a substantial drift in Santiago Marsal's instrument. Participation in this test at future workshops should be encouraged, given the importance of the total field measurement as it relates to the absolutes measurement.

References

[1] Jankowski, J., and Sucksdorff, C., 1996, Guide for magnetic measurements and observatory practice: International Association of Geomagnetism and Aeronomy, Warsaw

[2]Gem Systems, Inc., Overhauser Magnetometer, gemsys.ca/PDFDocs/GSM-19%20Overhauser%20v7.0.pdf (Accessed Online: October 15, 2008)