U.S. DEPARTMENT OF THE INTERIOR
U.S. Geological Survey

Development and testing of a tensor magnetic gradiometer system with trial monitoring near the Kilauea Volcano, Hawaii

by

Robert E. Bracken[1], Thomas P. Grover[2], and Gary Puniwai[3]

Open-File Report 98-773

1998

(paper edition)

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Trade names are used for descriptive purposes only and do not constitute endorsement by the U.S. Government.

[1]Mail Stop 964, DFC Box 25046, Denver, Colorado 80225, USA,
E-mail: rbracken@usgs.gov
[2]Denver, Colorado, USA
[3]Hawaiian Volcano Observatory, Hawaii, USA

CONTENTS

ILLUSTRATIONS

TABLES

Page

ABSTRACT

A prototype gradiometer system (TMGS) was designed and built for the purpose of detecting and measuring temporal variations in the magnetic gradient tensor.

The TMGS utilized four triaxial fluxgate magnetometers arranged on a tetrahedral sensor suspension apparatus. Each of the (twelve) axes operated independently of the others maintaining linearity, sensitivity, and dynamic range through a binning-style bucking coil arrangement. Thermal dependencies were handled by measuring sensor temperatures and by maintaining a constant temperature in an electronics housing.

A data-reduction technique was developed which utilizes a linear multiple input/output system operating in the frequency domain to remove gradient waveforms that are coherent with the geomagnetic field and temperature. The technique also addresses the overdetermined system of magnetic-field measurements providing a procedure for using the information from all twelve axes.

In an effort to detect and quantify volcanomagnetic signatures, the TMGS was field tested during a 10-month period near the Kilauea Volcano in Hawaii. Because of logistical constraints and a need to maintain the TMGS in a sheltered environment, a (cold) lava tube was selected as the monitoring site, which was at a location 5 km distant from a potential volcanomagnetic event.

Under the field circumstances, the TMGS was found to have a maximum sensitivity of about 0.2 nT/m rms over periods of a few hours to a few weeks (the periods of likely interesting volcanomagnetic events). Because the sensitivity was not great enough for the distance, detection of a volcanomagnetic event was precluded.

Nevertheless, the field location was an excellent proving ground and served to reveal aspects of the TMGS which can be improved. Many of the improvements were made after the field test; others remained for future design changes.

INTRODUCTION

During 1992 through 1996, the U.S. Geological Survey (USGS) in conjunction with Rust/Geotech Inc. developed a prototype tensor magnetic gradiometer system (TMGS) for measuring magnetic signatures from near-surface objects, structures, and processes. The impetus for developing this technology comes from an increasing need to define more precisely various attributes of buried magnetic sources. Advantages offered by TMG systems open them up to a wide variety of applications including the characterization of volcanomagnetic effects leading potentially to predictors of volcanic activity.

Because volcanoes pose real dangers which can affect large populations, the Volcano Hazards Program of the USGS, in an effort to further technologies for monitoring and predicting volcanic behavior, funded a monitoring experiment using the prototype TMGS. The TMGS (figure 1) was deployed from June 12, 1994 to April 3, 1995 on the Kilauea Volcano in Hawaii through cooperation of the Hawaiian Volcano Observatory (HVO).

The TMGS is a geophysical instrument which has characteristics applicable to the measurement of volcanomagnetics. Its gradiometer aspect gives it the capability of characterizing nearby magnetic events while suppressing interference from distant geomagnetic activity. This characteristic makes it possible to separate small magnetic variations caused by nearby volcanic activity from the normal and much larger magnetospheric chatter.

The tensor aspect of the TMGS gives it the unique ability to locate magnetic sources and characterize them. Magnetic fields contain more information about their source material than is typically seen by standard magnetic instruments. For example, total field magnetometers used in standard magnetic surveys measure the field strength but do not reject interfering fields from distant sources. Total field gradiometers can suppress distant fields and point to nearby sources but cannot completely define the sources. The magnetic tensor however, in addition to

Figure 1. Picture of the Tensor Magnetic Gradiometer sensor apparatus monitoring near an active lava tube on the coast in Hawaii Volcanoes National Park. (The camera is pointing south.)

measuring the same quantities as the total field systems, also defines the locations (in three dimensions) and magnetic moments of nearby sources.

Therefore, if sufficient sensitivity can be attained, the data from a monitoring TMGS could be used to locate, characterize, and possibly map the shape of a volcanomagnetic event. This capability could become very useful in characterizing volcanic activities preceding eruptions as well as becoming a powerful tool in the general study of volcanoes.

This report presents descriptions and discussions of the monitoring experiment, the prototype TMGS, the monitoring data, and results.

DESCRIPTION OF THE EXPERIMENT

Geophysical techniques consist of methodologies and instrumentations that discern unseen structures and processes. Any process that alters a field or makes a wave, basically sends out a signal. If someone knows the signal exists, chances are that a geophysical technique can be developed to measure it. The key is in making that technique sensitive and smart enough to discern the difference between the signal of interest and the other competing signals. Such is the relationship between TMG systems and Volcanomagnetics.

Volcanomagnetics

Volcanoes send out all kinds of signals, many of which are already being measured and interpreted to great advantage. Among these is a more subtle class called Volcanomagnetics. They have already been predicted to exist and observed (Zlotnicki and Le Mouel, 1988). What remains is to refine their measurement to the point where they can add to the picture already being painted of a volcano's inner workings.

Volcanomagnetics are simply magnetic fields produced by volcanic processes. They have three primary sources (Zlotnicki and Le Mouel, 1988). 1) One source is variations of rock temperatures near the Curie point. When temperatures rise above the Curie point, the rocks ability to hold a magnetic field is destroyed. As temperatures sink below the Curie point, the Earth's ambient field is frozen, so to speak, into the rock. Because the Curie point is well below the melting point of rock, changes in the motions of magma within the Volcano and cooling of lava flows on the surface can therefore cause magnetic variations. 2) A second source is from piezomagnetism which results from stress variations in the rocks. When the stress changes, a magnetic field emerges. 3) The third source, called electrofiltration, is also related to stress but acting on the water in cracks and faults or in the interconnected pore network of rocks. The primary phenomenon is the formation of an electric double layer at the solid-liquid interface. This double layer is made up of a layer of ions firmly attached to the solid wall and a more mobile diffuse layer of ions of opposite sign extending in the liquid phase. As stress varies within the massif, pore pressure changes. Resulting water circulation produces a potential difference between the solid-liquid interface, which causes changes in the magnetic field.

The Magnetic Field

The magnetic field is a potential field in the strictest sense of the word; it obeys Laplace's equations; it obeys Maxwell's equations; and it is a vector (not a scalar) field. That is to say, the magnetic field behaves under a well-defined set of rules and lends itself to various mathematical derivations. The field has characteristics of both magnitude and direction and may change as a function of time. Temporal variations in the magnetic field give rise to electric fields; and vice versa. All of these characteristics can be used to advantage in designing instruments that will discern locations, sizes, and extents of magnetic sources.

The basic source of a magnetic field is the dipole. Geologically, source materials contain an agglomeration of dipoles; and the field at any point outside the source is simply the vector sum of the individual fields produced by the dipoles. The agglomeration of dipoles is called magnetism and occurs in rock units as two significant kinds: remanent magnetism and induced magnetism.

Remanent magnetism is like a permanent magnet within the object. It is not significantly affected by the presence of external fields. Induced magnetism, on the other hand, occurs in response to an external field such as the geomagnetic field (GMF) and is more-or-less proportional to the external field strength. The induced field appears from within the object just as a remanent field would.

The geomagnetic field consists of a large constant component with a much smaller temporal component riding on top. Any rock units possessing induced magnetism will produce a new field which is proportional to the geomagnetic field. That is, their field will be correlated to the geomagnetic field. In contrast, volcanomagnetic sources are similar to remanent magnetism; their signature should be uncorrelated with geomagnetic variations. This characteristic can be quite useful in discerning their presence.

The magnitude of any field from a dipole decreases in proportion to the cube of the distance (1/r^3 rule). Therefore, the rate of change of a dipolar field as a function of distance decreases in proportion to the fourth power of the distance (1/r^4). That is, the gradient decreases more rapidly than the magnitude. Therefore, a device which measures gradient will respond to fields from nearby sources and tend to reject fields from more distant sources. If a magnetic gradiometer is placed near a volcano, it should sense preferentially the volcanomagnetics and reject the geomagnetic variations.

Because of the magnetic field's directional nature, the gradient is not simply a scalar quantity. The magnetic field has three orthogonal components; and each component follows the 1/r^3 rule. Also, the gradient of each component follows the 1/r^4 rule. Furthermore, for each component direction, there are three orthogonal gradient directions. In all, there are nine gradient components forming a 3x3 matrix which is also a second-rank tensor known as the magnetic gradient tensor. Because of constraints placed on static magnetic fields by Maxwell's equations, only five of those nine components are independent (Wynn and others, 1975).

The gradient tensor contains a large amount of information about nearby sources. If the signature of a single point source can be isolated, the tensor together with the three magnetic-field components will give the actual direction, distance, and dipole moment of the source. This procedure is known as dipole mapping (Wynn and others, 1975). Pedersen and Rasmussen (1990) discuss other characteristics of the tensor and suggest a number of geophysical applications. Many tensor characteristics may be of importance in volcano studies. Of obvious utility is the dipole mapping. With an appropriate monitoring device, isolated anomalies of temporal volcanomagnetic nature could potentially be mapped in three dimensions (figure 2) and cataloged according to magnitude.

Challenges

The process of obtaining the gradient tensor is not an easy one. Testimony to this statement is found in the lack of tensor gradiometers for common use. Several predictable difficulties must be surmounted in order to reach the sensitivity levels necessary for competitive use.

First, the gradients become quite small even at relatively short distances. For example, an expression from magmatic activity in a volcanic conduit 2 or 3 km distant has been modeled to be around 0.1 nT/m (personal communication, Tom Hildenbrand); the gradient of permanent and induced magnetic fields from a moderate sized stationary vehicle (Chevy Suburban) will be about 0.08 nT/m at 25 m. In order simply to detect the gradient, the signal-to-noise ratio must exceed 3 dB. If the dipole mapping algorithm is to return a reliable direction, the signal-to-noise ratio must be much higher.

Second, a tensor gradiometer device must have a tremendous dynamic range. That is, it must be able to maintain picotesla-per-meter precision in the presence of a 50,000-nT geomagnetic field containing 100-nT variations. These represent dynamic ranges of 117 dB and 63 dB respectively if 0.1 nT/m is to be detected.

Third, because each sensing element within a gradiometer is subject to the same huge geomagnetic field, a large common-mode signal is present. It places severe constraints on mechanical and thermal rigidity. For example, in order to maintain 0.1 nT/m, the attitudes of two vector sensing elements must remain within 2 μrad of each other. In perspective, the deflection cannot exceed 1 m in 500 km! The common mode is quite possibly the most difficult of all constraints. If it did not exist, the first constraint could be lessened by increasing the separation between sensing elements.

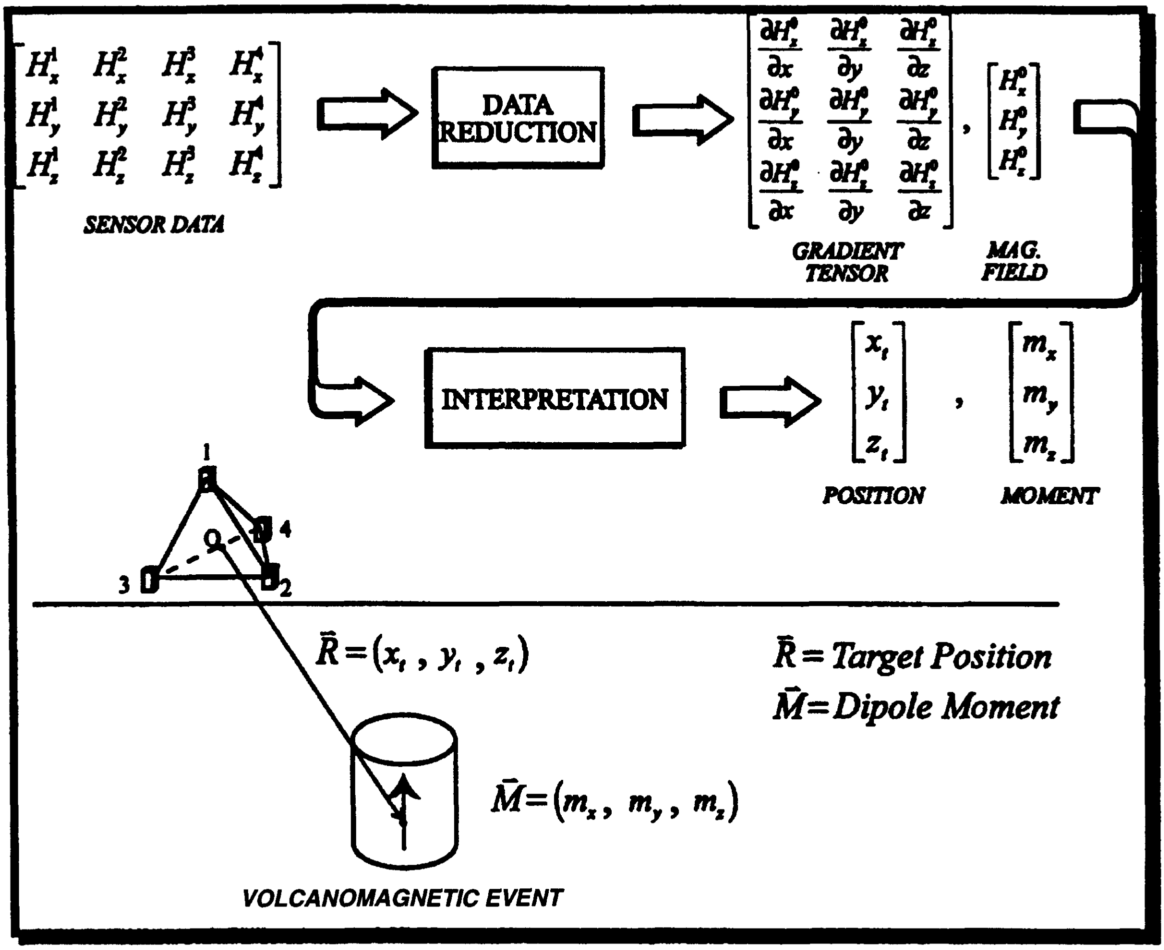


Figure 2. Diagram of mapping a volcanomagnetic event using the magnetic gradient tensor and dipole mapping algorithm.

Objectives

The overall objectives of this experiment are essentially: a) to build and test a prototype tensor magnetic gradiometer system (TMGS) capable of long period monitoring, and b) to test the instrument by gathering magnetic gradient data appropriate for evaluating volcanic processes. These objectives may be broken down into the following:

1) Build a TMGS.
2) Derive basic calibration coefficients for the TMGS.
3) Discover techniques for refining stationary TMGS measurements including derivation of methods and coefficients which require long periods of data collection.
4) Evaluate the instrument stability and noise content during an extended time period including effects from geomagnetic daily variations, thermal variations, and overall magnetometer stability.
5) Evaluate the instrument deployability.
6) Evaluate the instrument reliability and serviceability in an extended monitoring context.
7) As a proof of principle, observe magnetic gradients caused by magnetic induction, electromagnetic induction, and volcanomagnetic effects.

Following is a list of criteria by which to evaluate success of this experiment:

1) An evaluation of the prototype TMGS' suitability for volcanomagnetics should be produced;
2) A specific data reduction technique with parameters for this instrument should be discovered;
3) Signal and noise levels resulting from anything that is not a real gradient should be reduced to 0.1 nT/m rms per tensor component over a 3 dB band of 1.7 to 280 μHz; and
4) Positive identification of a volcanomagnetic event should be made.

Strategy

The approach is to build the TMGS from a set of four Narod Ring-Core Triaxial Fluxgate magnetometers. These magnetometers have been selected because they are known for their sensitivity and good results in magneto-tellurics and geomagnetic observatory applications.

The TMGS is to integrate design characteristics which compensate for thermal and mechanical instabilities and address the inherent common-mode problem requiring a 6-order dynamic range. The magnetometers are known to possess a sufficient dynamic range with some questions as to how they will be affected by thermal variations. A tetrahedral structure has been chosen to mount the magnetometer heads; this structure is extremely stable both mechanically and thermally. The magnetometer heads are to be thermally insulated and thermistors installed to monitor their temperature. The electronics are to be encased in a box together with a data acquisition system and environmental controls.

Once the system is built, the magnetometers and the structure are to be field tested and calibrated to the best attainable levels. Noise levels are predicted to be better than 1 or 2 nT/m rms with a hope of reaching 0.1 nT/m.

The prototype TMGS is to be deployed for long-term monitoring near the Kilauea volcano in a sheltered location. The sheltered location must provide protection from sun, wind, rain, corrosive gases, and public observation while being close to volcanic processes and accessible for periodic maintenance. These requirements are to be met either by building a structure to house the TMGS or by finding a cold lava tube of appropriate dimensions and accessibility.

During and after the monitoring period, evaluations are to be made of the data; and the calibration coefficients are to be adjusted to reduce thermal sensitivities and geomagnetic daily variation influences.

Any real gradients caused by magnetic induction, electromagnetic induction, or volcanomagnetic effects and being 3 dB or more above the noise floor should become discernable as a proof of principle. Larger signatures may contain enough information to allow location of their source.

DESCRIPTION OF THE INSTRUMENTATION

Principles of Operation

The prototype TMGS utilizes four tri-axial magnetometers suspended at known spacings and attitudes on the vertices of a rigid tetrahedral platform. The gradient tensor is calculated from vector differences in magnetic readings using an assumption that the magnetic field has negligible curvature.

Negligible curvature is the assumption that gradients do not change significantly within the volume of the sensing apparatus. This condition will result when the gradient source is distant compared to the spacing between sensors. The TMGS has a sensor spacing of about 1 m and the sensitivity for each sensor is about 0.01 nT per square-root hertz. If typical gradients were less than 1 nT/m, then curvature from any source more than 25 m away would not have a significant effect. Therefore, a restriction (Table 1A) is implied that the TMGS should be used only for sources more distant than 25 m. The restriction should pose no problem for remote sensing of volcanomagnetics.

Each magnetometer and each axis of each magnetometer operates independently; there is no mechanism for mutual removal of the common-mode field. Because of this characteristic and the fact that only five gradients are necessary to define a magnetic tensor, the system becomes overdetermined having nine gradients measured. This redundancy can be used during data reduction to improve the signal-to-noise ratio.

General Physical Description

The TMGS is comprised of four magnetometers, a sensor suspension apparatus, an electronics box, a data acquisition computer, and a few ancillary items (figure 3). The magnetometer sensor heads are attached to the suspension apparatus and connected to the electronics box via a bundle of cables 30 m in length.

Ancillary items include an independent temperature monitor, a power supply, four 12-V deep cycle batteries, a cart for the electronics box, a platform for the suspension apparatus, and during the experiment, a solar-panel battery-charging system.

The Magnetometers

Origin and History

The magnetometers used in this prototype TMGS are called ring core fluxgate magnetometers (RCM). This design was originally developed by the National Aeronautics and Space Administration for use in the MAGSAT spacecraft (Acuna and

Table 1. LISTING OF THE SOURCE, CHARACTER, AND REALIZABLE GRADIENT EFFECT OF KNOWN INSTRUMENT-GENERATED NOISE

NOISE OR ERROR			PRIMARY MANIFESTATION				GRADIENT CHARACTER				REMAINING NOISE	
REF	TYPE OF ERROR	SUB-SYSTEM	AMPLITUDE	TYPE	WAVELEN	DEPENDENCY	EFFECT	DEPENDENCY	NON-LIN	REMEDY	RMS NT/M	WAVELEN
						Removable						
A	Field Curvature	TMGS	VARB nT	p2p	VARB	Source DIST	False GRAD	Source DIST	??	Increase Source DIST	0	SCS-YRS
B	Circuit Voltage	RCM CIRC	1 nT/V	p2p	HRS-INF	RCM Input v	GRAD Drift	RCM Input v	Stepwise?	Regulate Power Supply	0	DYS-WKS
C	Heterodyne	RCM CIRC	4 nT	p2p	SCS-HRS	RCM Drive FQ	Sine Wave	RCM Drive FQ	??	Phase-Lock Oscillators	0	SCS-HRS
F	Bin Size	RCM CIRC	2 %	±	INF	RCM CIRC	Leak GMF	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
G	Deviation Coefficient	RCM CIRC	3 %	±	INF	Bin Number	Leak GMF	GMF VARs	None?	Remove GMF-CORR WAVES	0	MNS-DYS
H	Zero Voltage	RCM SENS	2.5 V	±	INF	Bin Number	Leak GMF	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
I	Inorthogonality	RCM SENS	1.5°C	±	INF	RCM SENS	Leak GMF	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
J	Spatial Blurring	RCM SENS	8.6 cm	p2p	INF	RCM SENS	Leak GMF	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
K	Bucking Coil Interference	RCM SENS	1 nT	±	MOS-YRS	Bin Number	Leak GMF	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
O	Cross-Field Interference	RCM Core	?? %	p2p	MNS-DYS	Core Alloy	Leak GMF	GMF VARs	??	None	??	MNS-DYS
P	Cross-Field Instability	RCM Core	100 nT	p2p	Step	Core Design	MF VAR?	Thermal PMPG	Yes	Avoid Jarring	0?	??
R	Thermal Deflection	TESSA	0.2 nT/°C	p2p	HRS-DYS	Outside TEMP	MF VAR	Outside TEMP	None?	Remove TEMP-CORR WAVES	0	HRS-DYS
T	Dimensional Imperfections	TESSA	0.2 cm	p2p	INF	TESSA DIMENS	Leak GMF	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
U	Angular Imperfections	TESSA	0.5°C	±	INF	TESSA angles	Leak GMF	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
Y	Multiplexing	Morris	0 nT	p2p	SCS	MUXER	None	MUXER	None	Not Needed	0	SCS
BB	Erratic Morris TEMP	Morris	1.3°C	p2p	HRS-DYS	Unknown	MF VAR	Morris TEMP	None?	Hold Morris TEMP Steady	(see REF D)	
FF	Nearby Gradient Sources	Location	0.06 nT/m	p2p	MNS-DYS	KOENGSB Ratio	UNWNTD GRAD	GMF VARs	None	Remove GMF-CORR WAVES	0	MNS-DYS
						Non-Removable Short Wavelength						
L	Core Noise	RCM Core	0.1 nT	rms	<17 MNS	Core Noise	HF Noise	Core Noise	??	None	0.1	SCS-MNS
X	A/D Conversion Precision	Morris	0.04 nT	p2p	SCS	A/D Precision	HF Noise	A/D Accuracy	Random	Low-Pass Filter	0.014	SCS
Z	Aliased Magnetic Field	Morris	0.07 nT	p2p	SCS	HF MAGN Field	HF Noise	HF MAGN Field	None	Low-Pass Filter	0.025	SCS
						Non-Removable Mid Wavelength						
D	Circuit Thermal Drift	RCM CIRC	0.2 nT/°C	p2p	HRS-DYS	Morris TEMP	MF VAR	Morris TEMP	??	Hold Morris TEMP CONST	0.09	HRS-DYS
E	Sensor Thermal Drift	RCM SENS	0.3 nT/°C	p2p	HRS-MOS	SENS TEMP	MF VAR	SENS TEMP	0.01 nT/°C	Remove TEMP-CORR WAVES	0.03	HRS-MOS
N	Core-Field Non-Linearity	RCM Core	0.2? nT	p2p	INF	Core Alloy	Leak GMF	GMF VARs	0.04 %	None	0.015?	MNS-DYS
S	Humidity Deflection	TESSA	3? urad	p2p	DYS-WKS	Humidity	MF VAR	Humidity	Yes?	None	0.064?	DYS-WKS
W	Sensor-Thermistor Non-LIN	THRMSTR	2 %	±	INF	CIRC Design	TEMP CORRLN	SENS TEMP	0.012nT/°C	Calibrate THRMSTRs	0.04	HRS-WKS
AA	Aliased DC/DC Converter	Morris	0.4 nT	p2p	SCS-YRS	DC/DC FQs	RANDM Noise	DC/DC FQs	Random	Digital Filter Output	0.14	HRS-YRS
CC	Input Voltage	Morris	0.23 nT/m	p2p	DYS-WKS	Battery v	MF VAR	Battery v	No	Hold Battery v Steady	0.08	DYS-WKS
						Non-Removable Long Wavelength						
M	Core Aging Drift	RCM Core	1.5 nT	rms	MOS-YRS	RCM Core Age	LF Drift	Core Age	Probable	None	1.5	MOS-YRS
Q	Mechanical Deflection	TESSA	1.7 urad	±	WKS-MOS	MAT Strength	LF Drift	MAT Strength	Yes	None	0.036	WKS-MOS
V	Sensor-Thermistor Drift	THRMSTR	1°C	p2p	MOS-YRS	THRMSTR Design	LF Drift	Drift Rate	Yes?	None	0.1	MOS-YRS
DD	Platform Rotation	TESSA	4400 urad	p2p	MOS-YRS	PLATF Fatigue	LF Drift	TESSA ATT	Yes	Remove From Local GRAD	0.18	MOS-YRS
EE	Platform Translation	TESSA	0.44 cm	p2p	MOS-YRS	PLATF Fatigue	LF Drift	TESSA LOC	Yes	Remove From Local GRAD	0.03	MOS-YRS

Abbreviations Unique to this Table

% - Percent
< - Less Than
? - uncertain statement
?? - unknown
ATT - Attitude
CIRC - Circuit
CONST - Constant
CORR - Correlated
CORRLN - Correlation
DC/DC - dc-to-dc Converter
DIMENS - Dimensions
DIST - Distance
DYS - Days
FQ(s) - Frequency(s)
GMF - GeoMagnetic Field
GRAD - Gradient
HF - High frequency
HRS - Hours
INF - Infinity
KOENGSB - Koenigsberger
LF - Low frequency
LIN - Linearity
LOC - Location
MAGN - Magnetic
MAT - Material
MF - Mid frequency
MNS - Minutes
MOS - Months
MUXER - Multiplexer
PLATF - Platform
PMPG - Pumping
RANDM - Random
REF - Indexing Reference
SCS - Seconds
SENS - Sensor
TEMP - Temperature
THRMSTR(s) - Thermistor(s)
UNWNTD - Unwanted
VAR(s) - Variation(s)
VARB - Variable
WAVELEN - Wavelength
WAVES - Waveforms
WKS - Weeks
YRS - Years
v - Voltage

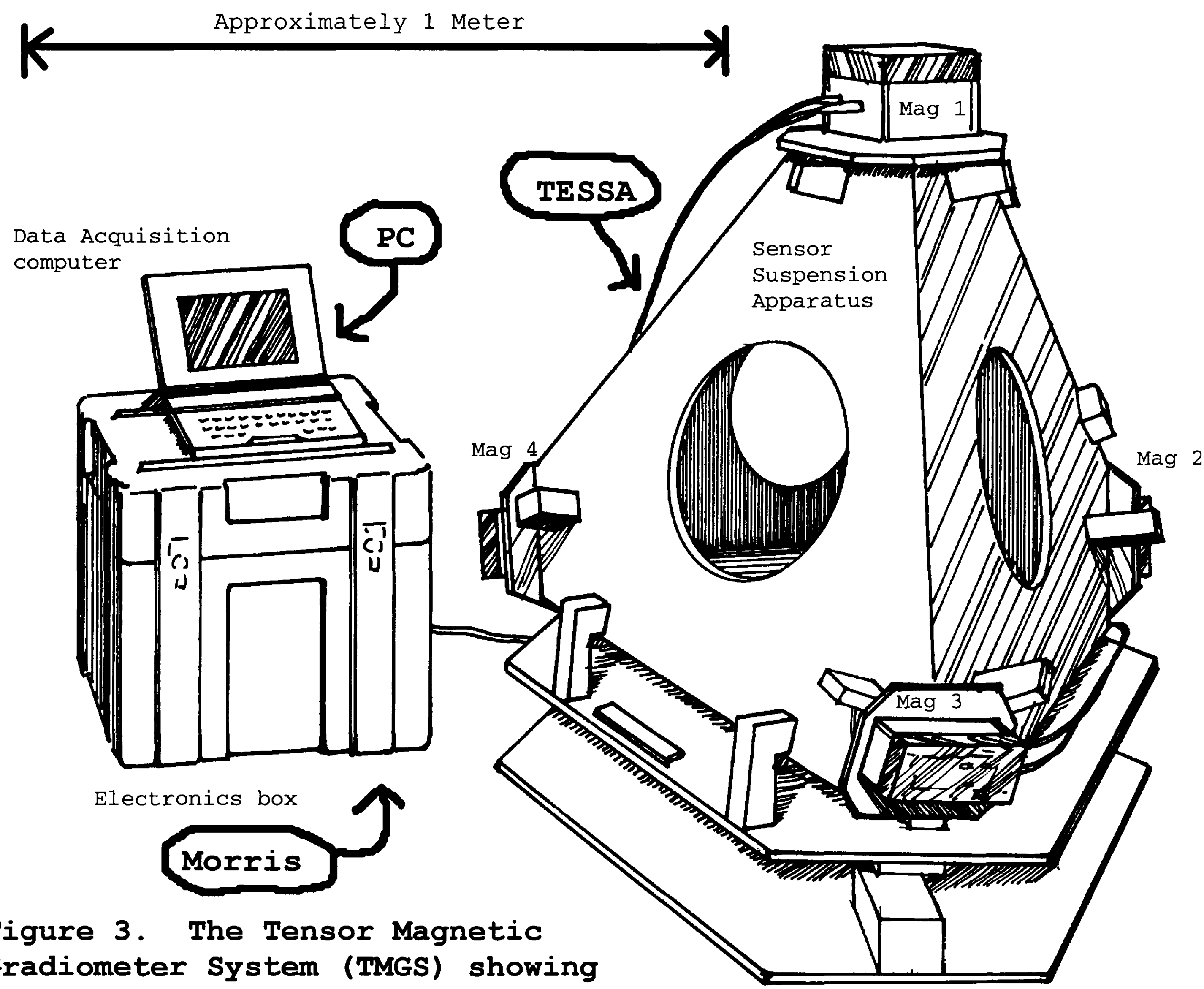


Figure 3. The Tensor Magnetic Gradiometer System (TMGS) showing the sensor apparatus (TESSA), the electronics box (Morris), and the data acquisition computer (PC).

others, 1978). The design was later copied by Narod Geophysical and developed for the U.S. Geological Survey for use in ground-based magnetic observatories (Narod, 1987). All four of these units were obtained directly from Narod Geophysical.

Justification for Use of Ring Core Magnetometers

The RCM was selected as the basis of the TMGS for a number of reasons: it is a vector sensor which, of course, is required; it is tri-axial which allows three directional components to be obtained on one substrate; it has a large dynamic range because of the bucking coil system; it has low noise because of the ring core design and alloy; and it is relatively inexpensive. Also, the manufacturer had published very low noise and drift rates (Narod, 1987).

At the time of selection, vector magnetometer technology had not developed significantly beyond fluxgate sensitivity levels (except low-temperature SQUIDs which are cumbersome to operate as noted by Nelson, 1988). Therefore, a high sensitivity fluxgate seemed to be a good choice. In addition, the RCM had been used with good success in the U.S. Geological Survey's magnetic observatories (personal communication with Bill Green, USGS); and had been used successfully in collecting magneto-telluric data (personal communication with Vic Labson, USGS).

Physical Description

The magnetometers are a fluxgate design which uses ring-shaped core geometry to improve signal-to-noise ratios and uses bucking coils to improve dynamic range and linearity. The sensor unit contains three orthogonal axes built together on a mutual substrate of white MACOR (Corning Glass Works trademark) being about 10 cm in length and weighing 0.5 kg (figure 4). Details of the original MAGSAT RCM are discussed in Acuna and others (1978). It is housed inside a plastic insulated field box. The sensor connects to a set of three circuit boards via a 30-m cable. The 12 circuit boards for all four magnetometers are housed together in an electronics box and kept at a distance from the sensors.

The coordinate system used is right-hand orthogonal with positive x pointing toward the front, positive y pointing right, and positive z pointing down. If rotated into an Earth reference frame, these directions would become north, east, and down.

Functional Description

Each magnetometer actually functions as three independent single-axis fluxgates oriented in mutually orthogonal directions. When a magnetic field of arbitrary direction is present, each axis senses only the magnitude of the field component which aligns with its direction. The three field-component magnitudes, being mutually orthogonal, sum vectorially to the original field.

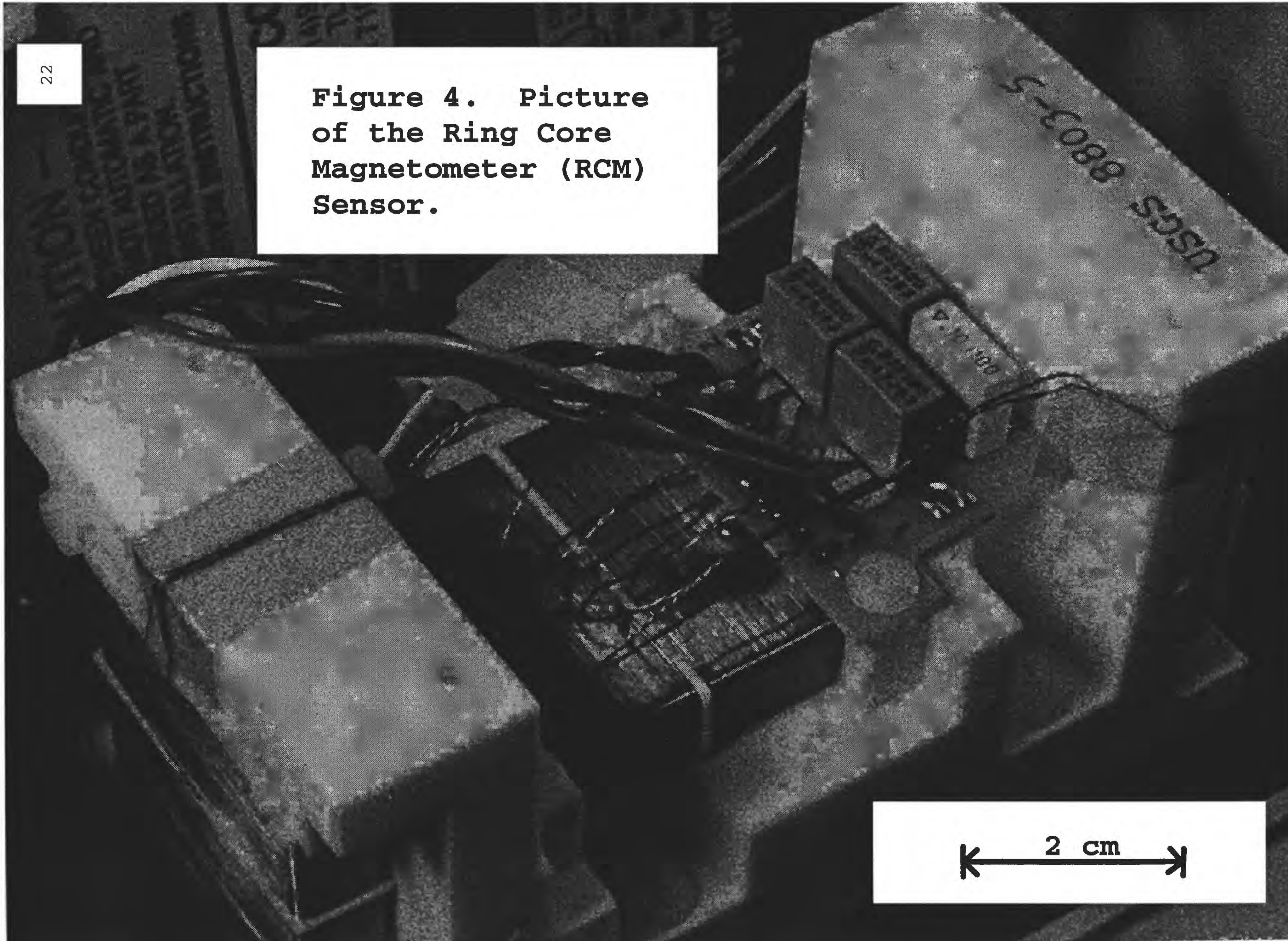


Figure 4. Picture of the Ring Core Magnetometer (RCM) Sensor.

When the core in one of the axes senses a field strength larger than a certain threshold, a bucking field produced by the bucking coil is changed in stepwise fashion to reduce the core field. In this way the core field is always kept small giving improved dynamic range; and the core operates within the most linear part of its range.

The bucking fields are called bins and each level of bucking-field strength or bin value is identified with an integer called a bin number. The bin value is equal to the bin number multiplied by a quantized amount called the bin size or bin coefficient. The nominal bin size is 500 nT for magnetometers 1 and 2, and 327.68 nT for magnetometers 3 and 4. This difference in bin size between the two sets of magnetometers is not a TMGS design requirement; it is simply a characteristic of the set of magnetometers utilized in the prototype TMGS.

The core senses the difference in magnetic field strength between the field component and the bin value. This difference or deviation is returned as a proportional analog voltage called the deviation voltage. The constant of proportionality, called the deviation coefficient, is nominally 100 nT/V.

The magnitude of each field component is then obtained by multiplying its bin number by the bin size and adding its deviation voltage multiplied by the deviation coefficient.

Electrical Description

The interfacing scheme of the RCMs with the electronics box is given in figure 5, a block diagram of the TMGS' electrical configuration. The bin number is passed directly to the data acquisition system in digital form. The core is driven into saturation using a 15.625-kHz signal. Magnetic fields cause imbalances in the core which then, due to the fluxgate design, produce a harmonic modulation signal at 31.250 kHz. The modulation signal, which is proportional in amplitude to the magnetic field strength, is detected and converted to the deviation-signal voltage.

Before being fed to the data acquisition system, the deviation signal is passed through a low-pass analog filter. The filter has a 3-pole Butterworth characteristic with a selectable cut-off frequency. For this experiment, the frequency was chosen to be 1 Hz.

The power requirement for each magnetometer is nominally 170 mA dc at 12 V. Although input voltages may vary up to 16 V, stable data can only be obtained with a well regulated input voltage. Tests have shown that the deviation signal changes by about 1 nT per volt for input above 12 V (Table 1B) and 10 nT per volt for input below 12 V. Because of this effect, the magnetometer input voltage for the TMGS is regulated well above 12 V at a constant 12.50 V.

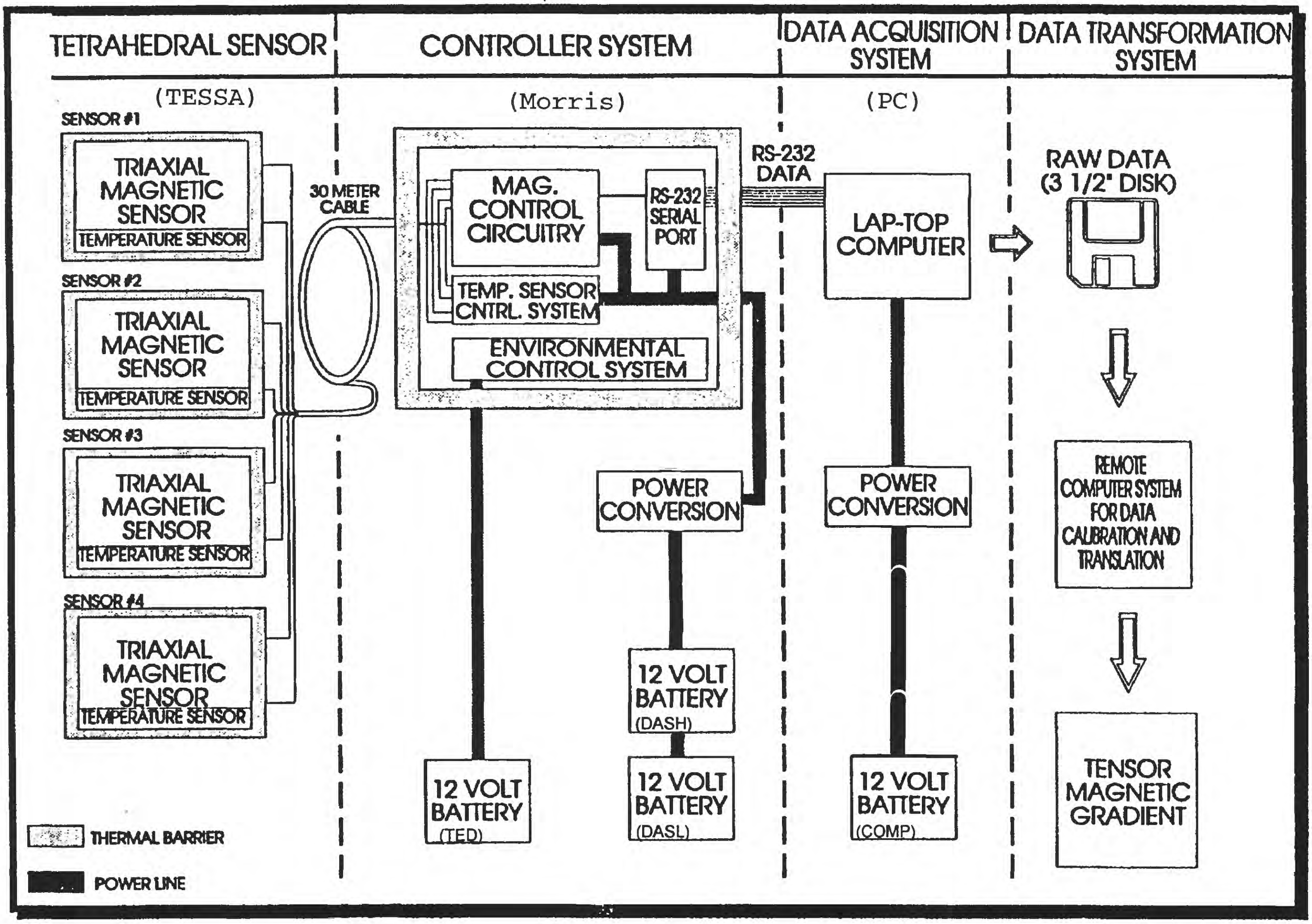


Figure 5. Block diagram of the TMGS main systems showing the magnetometer sensors and electronics, sensor thermistors and control circuits, the data acquisition system, the data acquisition computer, the thermal control systems contained in Morris, and the input power systems.

Tests have also shown that when sensors or boards from two or more different magnetometers are placed in close proximity (less than 2 m), the core drive signals interact. The interaction causes a heterodyne that can compromise the deviation signal by several nanoteslas at unpredictable frequencies (Table 1C). Because of this effect, the oscillators in all four magnetometers have been phase locked with magnetometer 1 and operate at precisely the same frequency.

Thermal Stability

Tests have shown that thermal drift in the circuit boards (Table 1D) is about 0.2 nT/°C per axis. Because of the large number of components and digital nature of the circuit boards, it is believed that there may be a piecewise response to large temperature variations. Therefore, to minimize this drift, the circuit boards used in the TMGS are kept in a constant-temperature environment (Narod, 1987) at approximately 35°C.

Thermal drift for the sensors (Table 1E) is about 0.3 nT/°C per axis in a 30,000-nT field. Because of engineering constraints, the sensors cannot be kept in a thermally-controlled environment. Each sensor is therefore housed in a plastic box insulated with approximately R-5 equivalent and has a thermistor attached to the substrate. The insulation minimizes rates of sensor-temperature change and allows the thermistor to reflect a more accurate reading. Temperature correlated variations can then be minimized in post processing. The sensor drift has been measured and is known to be a non-linear function of temperature. However in most cases, departure from linearity should not exceed 0.1 nT over a 10°C temperature range.

Error Sources

Beyond the voltage, heterodyne, and thermal drifts, there are several other error sources which result in many types of errors at many different frequencies. Most of these errors are linear with respect to magnetic-field variations; they can be removed or compensated through a variety of methods. However, some of the errors have non-linearities or immeasurable dependencies which restrict or preclude options for removal. Following are descriptions of the known sources:

Linear Error Sources

Bin Coefficients. - The bin sizes (bin coefficients) may vary from the nominal values of 327.68 nT and 500 nT by as much as 2 percent (Table 1F). This variation represents a potentially huge constant error in a monitoring situation (600 nT in a 30,000-nT field). If all axes were perfectly aligned, the bin-size error would cause a simple constant offset of the gradient value. However, because the axes are not aligned, the bin error can behave as an errant amplitude multiplier upon rotation into a common coordinate system. As a result, up to 2 percent of geomagnetic variations can leak through to the gradient. This effect is linear with respect to magnetic-field variations.

Deviation Coefficients. - The deviation coefficients can vary from the nominal value of 100 nT/V by as much as 3 percent (Table 1G). If uncorrected, the effect is to allow 3 percent of geomagnetic variations to leak through to the gradient. This effect is linear with respect to magnetic field variations but indications are that the deviation coefficients may vary slightly as a function of bin number.

Zero Voltage. - The zero voltage is the amount of voltage still present in the deviation signal when the field component is perfectly canceled by the bin field (Table 1H). If the bin field is zero (bin number is zero), this condition would occur when there is no magnetic field component. The effect of a zero voltage is similar to a bin coefficient error. There is some evidence to indicate that the zero voltage changes as a function of bin number. Values of zero voltage have been found to range as high as 2.5 V (250 nT). This effect is linear with respect to magnetic field variations.

Inorthogonalities. - Ideally, the three axes in a tri-axial magnetometer would be perfectly mutually orthogonal. But, because of mechanical and electrical aberrations, a small percentage of the signal from one axis may be leaked to another axis. The effect can be stated as degrees of departure from orthogonality (Table 1I). The impact to a gradiometer is similar to the bin-size error and deviation coefficient error: geomagnetic variations will leak into the gradient. Tests have shown that the RCM may have up to 1.5° of inorthogonality resulting in a 2.6 percent leakage. This effect is linear with respect to magnetic field variations.

Spatial Blurring. - The RCM axes do not have coincident centers. That is, they are separated by a few cm, the x axis being in the center and the y and z axes being at opposite ends of the substrate (Table 1J). If the gradiometer is located in a gradient, the effect is to add a small error to each axis. This error will be indistinguishable from the zero-voltage error except that it will be independent of bin number. This effect is linear with respect to magnetic field variations.

Bucking Coil Interference. - The bucking coils have been arranged so as to minimize interference to other axes. However, there is known to be a small effect (Table 1K). Modeling has shown that it should never exceed 1 or 2 nT. The bucking coil interference will depend upon the bin number of the interfering axis. This effect is linear with respect to magnetic field variations.

Non-Linear Error Sources

Noise and Drift. - The manufacturer describes a 1/f noise (Table 1L) that results in errors of less than 0.1 nT over the 0.001-Hz to 100-Hz band (Narod, 1987). Also mentioned in personal communication with the manufacturer has been a noise level of 1/90 nT (0.011 nT) in 1-minute averages. In addition, there is a long-term drift (Table 1M) resulting from aging of the sensor winding (Narod, 1987) that would cause about 1.5 nT per year in a 30,000-nT field. These effects have immeasurable dependencies.

Core-Field Non-Linearities. - The binning design is supposed to keep core-field magnitudes within a small enough range that the core operates completely linearly as a function of core field. However, it is possible that a small non-linearity (Table 1N) may exist having the effect that the deviation coefficient would be dependent upon core-field magnitude. If in fact core-field non-linearities exist, it is likely that they would be restricted to a few tenths of a nanotesla.

Cross-Field Interference. - It is postulated that the measurement of a component may be adversely affected by the presence of a cross component (Table 1,O) in a way different from inorthogonality. The cross component may affect the responsiveness of the small dipolar regions within the core material. If this effect exists, it may be non-linear with respect to magnetic field variations.

Cross-Field Instability. - A very serious and intrinsic condition has been discovered within the RCM. Unfortunately, it was not known until after the monitoring experiment. Had it been known, a different design geometry for the TMGS would have been chosen which would have minimized the effects of the cross-field instability. Tests have shown that any axis with a substantial component magnitude and a 20 percent to 80 percent cross field magnitude can become unstable when jarred (Table 1P). Only a few special circumstances avoid this condition. The instability is a change in the measured component magnitude of up to 100 nT each time it is jarred (to the degree that occurs whenever someone picks up or moves the sensor). There does not seem to be any manifestation during periods of no mechanical motion or vibration. Nevertheless, a concern is raised that the instability may occur in small increments over time as the magnetometer sensor is pumped by thermal variations or small vibrations. This effect is definitely not linear and has unknown dependencies.

Sensor Suspension Apparatus

Physical Description

The sensor suspension apparatus is the unit to which the magnetometer sensors are connected. Its primary function is to support the sensors rigidly in the correct orientations and relative locations.

The sensor suspension apparatus, called TESSA (tetrahedral electromagnetic-sensor suspension apparatus), is a tetrahedron with the vertices truncated to provide flat mounting surfaces for the magnetometers. The four magnetometer sensor heads are inside boxes mounted on the vertex surfaces and separated in distance by about 1 m (figure 3).

TESSA is made from plywood and Corian (a trade mark plastic). The plywood, which forms the faces of the tetrahedron, is sealed against humidity with fiberglass resin and painted white to retard thermal-expansion rates. The Corian forms the mounting surfaces (called vertex plugs) and was chosen primarily because its thermal coefficients are similar to those of the plywood. The sensor boxes bolt onto the vertex plugs with non-magnetic brass bolts and stainless-steel alignment pins. The weight with sensors is about 50 kg.

When monitoring, TESSA is placed on a flat horizontal platform with the first vertex pointing up and the other three vertices forming a horizontal plane below the first (figure 6). The second vertex is magnetic north from the first; the third vertex is southeast; and the fourth is southwest. TESSA sits in this attitude on three legs attached to the horizontal side. Perspective may be gained by examining figure 1 where the second vertex is nearest the camera.

All four sensors are attached to TESSA with their z axes pointing toward the centroid of the tetrahedron and the sensor numbers matching the vertex numbers. The x axis of sensor 1 points magnetic north (figure 7); the x axis of sensor 2 points up and slightly north. The positive-x extensions of sensors 1 and 2 intersect at a point which is level with sensor 1 and north of TESSA. The positive-x extensions of sensors 3 and 4 intersect at the reflection about the centroid of the No. 1 / No. 2 intersection.

The platform upon which TESSA sits is designed to provide a horizontal surface with calibrated positioning posts for use during rotation calibrations. This platform also provides a space of about 1 m between the ground and TESSA. The space removes the sensors from extreme proximity to magnetic ground clutter.

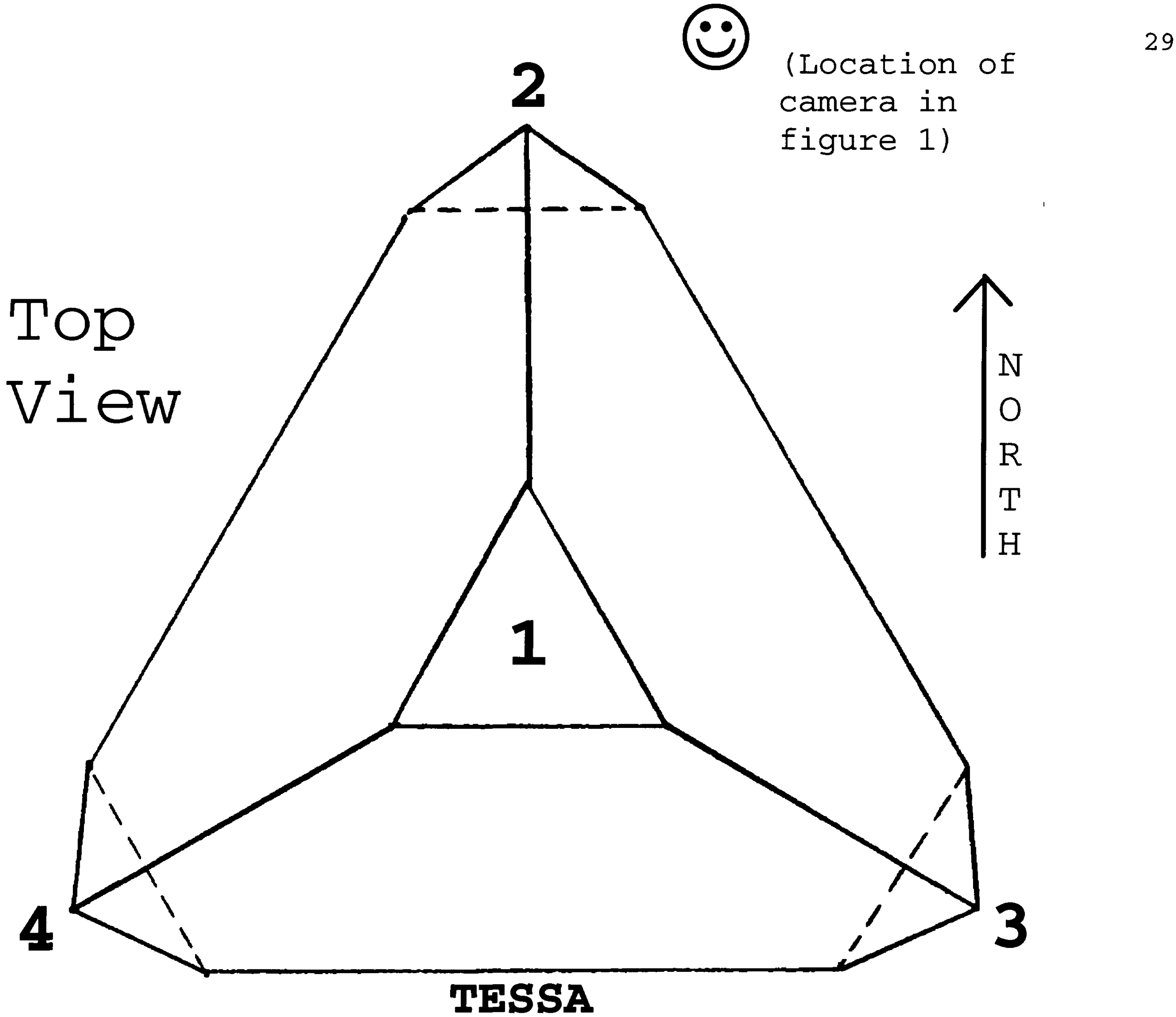


Figure 6. Diagram showing the numbering system used for the magnetometer sensors and vertex locations on TESSA.

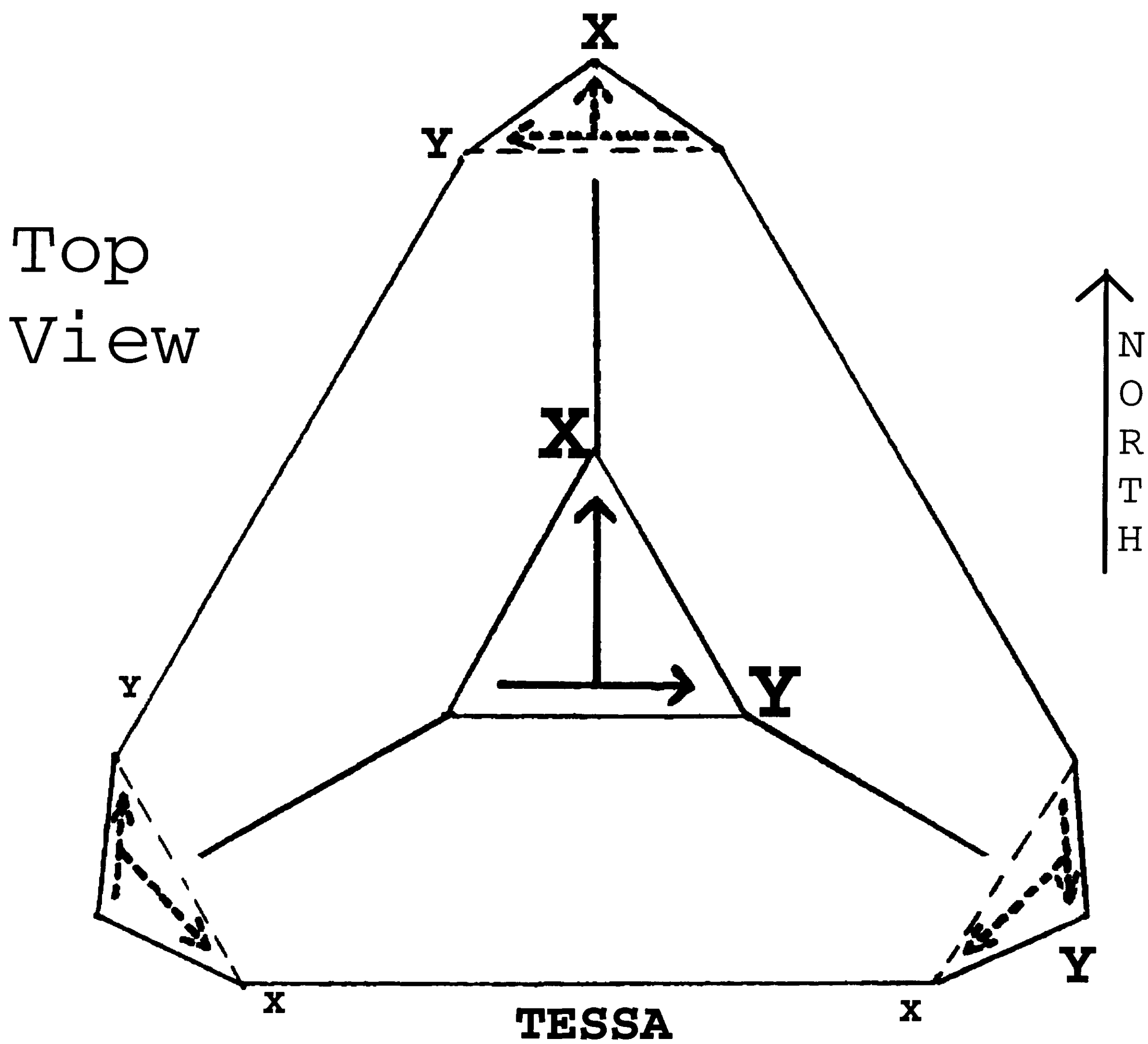


Figure 7. Diagram showing the attitudes of the sensor axes relative to each other and TESSA. The z axis of each magnetometer points toward the centroid of the tetrahedron.

Design Reasoning

The tetrahedral design was chosen in order to maximize rigidity and to provide the greatest symmetry. The tetrahedral shape is excellent for both of these requirements. Mechanical rigidity is important to minimize weight-related deflections. Symmetry is important for two reasons: 1) it encourages uniform thermal expansion which allows the least amount of deflection at sensor locations; and 2) it allows the sensor locations to be interchanged for calibration purposes.

The 1-m spacing was chosen as a compromise between two extremes. A larger dimension while providing higher gradient sensitivity (proportional to sensor spacing) also requires a heavier more cumbersome structure which is subject to greater deflections. A smaller dimension while providing a lighter structure and smaller deflections also reduces gradient sensitivity and invites interaction of the magnetometer bucking fields.

Rotation Calibration

The design of TESSA was partially chosen to allow for a special calibration procedure, called the rotation calibration (detailed procedure in appendix A), which systematically rotates each magnetometer into the positions and attitudes of the other three. The purpose is to balance each magnetometer by comparing what it reads directly to what another magnetometer reads in the same location and field. During the rotation calibration, TESSA is picked up and rotated 180° such that sensors 1 and 2 swap places and, simultaneously, sensors 3 and 4 swap. TESSA is then replaced with sensor 1 in sensor 2's location. This procedure is continued through a total of four rotations with readings taken at each stop until every sensor has been in every other sensor's location and sensor 1 is returned to the top. To accommodate the rotation calibration, legs have been put on all four sides of TESSA and handles on all six edges.

Stability and Error Sources

Mechanical and thermal rigidity are extremely important to developing a high precision TMG system. TESSA was field tested for both forms of rigidity. Under an unrealistically large load on the weakest part of the structure, deflection did not exceed 20 μrad. Thermal deflections were found not to exceed 7 μrad/°C. Under normal loads, it can be expected that the mechanical rigidity is great enough that artifacts would be well below 0.05 nT (Table 1Q). Thermal effects should not exceed 0.2 nT/°C. It is expected that thermal deflections (Table 1R) will be linear with respect to temperature.

Because wood can swell with moisture, it is possible that there could be a humidity dependency (Table 1S). Although measures were taken to seal the wood against humidity, it is unlikely that moisture can be held out. It is unknown how large or small this effect would be. However, the humidity in the monitoring location typically varied over a small range of 78 percent to 96 percent over several-day periods. Also, TESSA was kept in a cold lava tube which would have reduced the humidity variation rates and amplitudes. Additionally, wood does not respond rapidly to changes in humidity. Because of all these mitigating factors, it is reasonable to assume that the effect from humidity is small. However, it should not be ignored as a possible contributor to the error budget.

Ideally, TESSA would be engineered to such exacting specifications that a perfect virtual tetrahedron would be formed with vertices at the precise centers of all four magnetometer sensors; and the sensors would be oriented with perfect angles according to specification. In this case there would be no errors. In reality, the perfect virtual tetrahedron has been attained to within 2 mm (Table 1T) and relative attitudes at the vertices to within 0.5° (Table 1U). The legs have been measured and shimmed to maintain spatial locations of all four sensors also to within 2 mm during rotations.

During a rotation calibration the spatial precision can insure that each magnetometer reads the same field to within 0.2 nT in a 100-nT/m static gradient. The attitudinal error, however, is large enough to cause up to 250-nT component departures in a 30,000-nT field. Therefore, if all other calibration constants are known, the rotation calibration can be used to constrain constant attitudinal errors of each sensor.

Electronics Box

Physical Description

The electronics box, called Morris (figure 3), is a large grey field box about 60 cm on a side and weighing 23 kg with a large heat sink and fan assembly on the outside. Morris contains the magnetometer control circuitry (12 circuit boards), sensor-thermistor control circuitry, a data acquisition system, and an active thermal-control system (figure 5). The thermal-control system maintains the inside temperature at a constant 35±0.15°C.

There are three separate power systems requiring a total of four 12-V batteries. A main digital system uses two 12-V batteries in series with a center tap. Average current draw through each battery is about 0.7 A. A thermoelectric-device (TED) circuit requires one 12-V battery and may draw from 0 to 10 A. The average current draw depends on the outside air temperature: minimum occurs near 27°C; maximum is at the extremes of 0°C or 50°C. The data-acquisition computer uses one 12-V battery with an average current draw of about 0.9 A when the screen and disk are shut down.

During the experiment, eight solar panels were connected to the batteries in order to maintain their charge. The output voltage of the solar panels was 16 to 17 V and would raise the battery voltages to the same. During long periods of no sun, the batteries could become discharged to as low as 11.5 V. (A graph and table of the battery voltages are given in appendix I).

Sensor-Thermistor Control Circuitry

Four sensor thermistors are intended to return the temperatures of the magnetometer sensors (figure 5). Each thermistor is attached to an inner portion of a sensor substrate with thermal grease and silicone caulk. They operate at a fundamental frequency of about 40 kHz in order to avoid interference with the magnetometers (which operate at 31.250 kHz). The control circuit provides a scaled analog voltage (10°C/V) for input to the data acquisition system.

After November, 1994 a 5th thermistor was added to the circuit for measuring outside air temperature at TESSA's location. The outside thermistor is multiplexed at 15-minute intervals with the No. 4 thermistor.

These thermistors were chosen for their stability and precision. However, any thermistor will drift slightly (Table 1V) over time. These are expected to drift about 1°C per year. Also, the analog voltage is not linear (Table 1W) with respect to temperature. Tests have shown that in a 10°C temperature range, departures from linearity can approach 0.2°C. If uncorrected, this departure could result in 0.1-nT component errors.

Data-Acquisition System

All data channels are output to an internal data acquisition system (figure 5). It receives the 12 bin numbers through a parallel port from each of the four magnetometer-controller boards; the 12 deviation signals are received through a 50-kHz multiplexer from the magnetometer-filter boards; and the four analog thermistor signals are also received through the 50-kHz multiplexer. The data are then formatted and sent via an RS232 serial port to a lap-top computer for data processing and storage.

All analog signals are sampled at 5 Hz with a 16-bit A/D converter which ranges from -6.5536 to +6.5535 V. The 16-bit A/D conversion will produce a real accuracy within a couple of bits (Table 1X). Each bit is worth 0.02 nT making the sampling noise level below 0.04 nT.

In order to make the gradient measurements valid, all 12 deviation signals must be effectively sampled simultaneously. Although sampling is not actually simultaneous, the multiplexing period (Table 1Y) is so short that errors are vanishingly small: the entire 320-μs multiplexing period is at a frequency 11 octaves above the 1-Hz cutoff frequency of the analog (deviation-signal) filters.

The 2.5-Hz Nyquist frequency of the 5-Hz sampling period is only 1.3 octaves above the filter cutoff frequency. At 18 dB per octave (3-pole Butterworth), Nyquist frequencies will be knocked down only 24 dB; that is, Nyquist amplitudes will be reduced to about 1/15. Therefore any sustained magnetic signal with frequencies at or slightly above 2.5 Hz and amplitudes above 1.5 nT could cause aliasing (Table 1Z) with amplitudes above 0.1 nT. This possibility is only of minor concern because such signals are unlikely. The 1-Hz rather than a 0.1-Hz filter was chosen to facilitate periodic rotation calibration procedures.

Of greater concern than any of the above is a large noise source in the data-acquisition system. A faulty dc-to-dc converter (Table 1AA) dumps a huge 250-kHz square wave into the data-acquisition circuitry. It results in an apparently random noise of amplitude 0.1 to 0.4 nT superimposed on the digital data. Because it is injected after the filters, they are not able to remove it. Logistical constraints precluded the converter being replaced until after the experiment. However, steps were taken part way through to reduce the effect.

Thermal-Control System

Because of the need to maintain a constant temperature for the magnetometer circuit boards, an active thermal-control system (TED system) has been included in the design of Morris (figure 5). The system includes 1) complete R-10 equivalent insulation, 2) a thermoelectric heat-pump device and heat exchangers, 3) an inside fan for circulating air around the inside exchanger and circuit boards, 4) a fan for the outside exchanger, 5) an environmental-thermistor controller with thermistors for inside, outside, and heat-pump temperatures, 6) an environmental-thermistor data acquisition system, 7) a digital heat-pump controller, and 8) a palm-top computer for directing the heat-pump. The system requires an additional (independent) 12-V dc 10-A source to supply heat pumping power.

The thermal-control system can maintain the inside temperature at 35±0.15°C over an outside temperature range of 0°C to 50°C. However, during the experiment it seems that the temperature varied from 33.8°C to 35.1°C (Table 1BB); no explanation can be found except, possibly, there might be an air-pressure/ humidity connection. The gradient response has been tested over this range and found to be a long wavelength with amplitude up to 0.25 nT/m per component. Power supply voltage variations have been found not to affect the inside temperature.

Data Acquisition Computer

The output of the data acquisition system is delivered via RS232 to a lap-top data-acquisition computer (figure 3) for data processing and storage. The data are stored in raw form in a disk file. Then they are transferred weekly to a 3.5" disk for permanent storage.

During the first half of the experiment, the program recorded only every 600th sample (1 sample every 2 minutes). However, the dc-to-dc converter noise became too difficult to remove by filtering. During the second half of the experiment, a modified data acquisition program was installed which stored the average of 600 samples. The averaging reduces the converter noise to 0.05 nT or less in the higher frequencies. Unfortunately, the nature of aliasing leads one to suspect that, even with the averaging, there may remain 0.4-nT long wavelengths. The averaging interferes slightly with the computer clock which increases the sample interval to about 120.8 seconds (see appendix F).

Instrument Error Budget

Additional Errors

The extreme voltage variations from the solar panels caused an error to manifest (Table 1CC) the source of which is unknown. As the voltages of all four power batteries are raised to 17 V or lowered to 11 V, gradient variations of around 0.1 nT/m per component can be seen.

The attitude of TESSA's platform is known to have changed about 0.25° over the duration of the experiment; the position probably changed slightly as well. If there was no gradient present, these variations would have produced no gradient error. However, a gradient of about 110 nT/m with field curvature of about 20 nT/m/m was present in the space occupied by TESSA during the experiment. Therefore, a rotational error (Table 1DD) proportional to the gradient probably exists with maximum amplitude of 0.49 nT. A smaller translational error (Table 1EE) proportional to field curvature probably also exists with maximum amplitude of 0.09 nT/m. Both of these gradient errors should be long wavelength but may contain steps resulting from platform-strain tares or rapid settling. They should be primarily dependent upon mechanical strains in the platform; but, some portion may also have removable thermal dependencies.

Error-Budget Tabulation

A list of the source and character of each known instrument noise and error is presented in table 1. By careful examination of this list, the expected gradient noise can be deduced. On the left side, the characteristics of each noise or error are given as they have been described in this section; on the right, the expected effect in a gradient is given in rms amplitude and wavelengths.

The total rms amplitude of the errors in a given band is found by summing the powers: squaring the individual rms amplitudes, summing them, and then taking the square root. The peak-to-peak value is sometimes more meaningful for visualizing a graphical representation. It is twice the rms value divided by 0.707.

Bounds for an Expected Event

Several noise evaluations are possible from table 1. The largest value would be obtained if none of the temperature or geomagnetic-field correlated errors were removed. Because removing these errors is part of the data reduction procedure, this value is not of great interest (it would be quite large and meaningless).

The next largest error would be obtained from the assumption that all frequencies are necessary in the evaluation and all uncorrelated errors have equal likelihood of existence. This error would be 1.5 nT/m rms (4.3 nT/m p2p).

Because volcanomagnetics events are expected to occur over periods of a few hours to a few days, the band can be limited and only those noises within that band selected. The band-limited error would be 0.20 nT/m rms (0.57 nT/m p2p).

If it happens that the dc-to-dc converter error does not alias to low frequencies, the error can be further reduced to 0.15 nT/m rms (0.41 nT/m p2p). Finally if the possibly erroneous humidity estimate and core-field non-linearity are removed, the error would become 0.13 nT/m rms (0.37 nT/m p2p).

These estimates are quite useful because they give bounds for identifying events that are based on known instrument characteristics. Any "event" with a peak-to-peak amplitude smaller than 0.37 nT/m should be immediately suspected as instrument noise. Any event larger than 0.57 nT/m p2p should be examined closely as potentially real.

Future Improvements to the Error Budget

In future experiments, most of the mid-wavelength group of errors can be eliminated with simple re-working of some systems. They are as follows: circuit-board thermal drift, sensor-thermistor nonlinearity, aliased dc-to-dc converter, and input voltage error. With these removed, the only noise remaining is from non-linearities in the sensor thermal drift (0.03 nT/m rms or 0.08 nT/m p2p). However, because the 0.03-nT/m level is approaching the basic RCM noise floor, it is likely that there is an entire suite of smaller unlisted noises which would manifest at that level.

DATA ACQUISITION AND SELECTED RESULTS

Site Selection

The process of site selection began in 1993 when the staff at the Hawaiian Volcano Observatory (HVO) began supplying general wisdom for placement of the instrument, descriptions of recent volcanic activity, maps of potential TMGS site locations, and surface samples for magnetic properties analysis. However, the final selection was made a few days before the beginning of the data acquisition period.

The criteria for site selection included: proximity to volcanic activity, shelter from the elements and corrosive gases, accessibility for periodic maintenance, remoteness from cultural influences, and remoteness from interfering gradients. Ideally, the site would have been chosen very near the Kilauea crater or on the East Rift Zone. However, in order to reduce instrument noise, a strong need was perceived to shelter the TMGS from the elements.

Because of logistical constraints, a suitable shelter could not be built. Therefore, a cold lava tube was chosen about 4.5 km due south of the axis of the East Rift Zone and 13.5 km southeast of the Kilauea crater. Because of a limited selection of cold lava tubes and the clear priority of accessibility, this location became the best compromise among the choices.

The location of the centroid of TESSA was lat 19°20'01.7"N., lon 155°11'18.6"W., and 754 m elevation; or 245 m due north of the mile-8 marker on the Chain of Craters Road in Hawaii Volcanoes National Park, HI and 4.6 m below the ground surface. The lava tube is accessed from a collapse 10 m north of TESSA's location. In cross section, the lava-tube was about 2.5 m high and 3 m wide. The centroid was approximately centered vertically and horizontally.

Morris was kept above ground on a specially designed cart about 20 m away from TESSA. Because Morris has its own environmental control system, environmental factors were not a serious noise contributor. Nevertheless, a tarp had to be kept over the Morris assembly to shield it from weather.

Site Suitability

This site selection was excellent from the standpoint of protection from the elements. The experiment has shown that, because of instrument sensitivities, there would have resulted devastating effects from large temperature variations, moisture, wind noise, differential solar heating, and the like. This result confirms that making the underground selection first priority was the best that could be attained.

Lack of proximity to volcanomagnetics probably precluded seeing any astounding effects. The nearest activity would probably have been about 5 km. An event visible to the instrument would have to be five times larger at 5 km than at 3 km. However, a closer site would not have afforded appropriate protection and likely would have increased instrument noise by more than a factor of five.

With the seclusion and moderate distance from the road, cultural noise was virtually non-existent. Yet it was close enough that repeated visits were not a formidable task. Albeit, having to hand-carry 300 kg of equipment nearly a quarter of a kilometer during set-up and take-down was undoubtedly a bit taxing.

Remoteness from interfering gradients was not attained. However, because of the magnetic basalts composing the terrane, no other site would have afforded any advantage.

Tests on rock samples from the area are presented in table 2. Because the samples were measured in random orientations, the remanent component is much smaller than it should be; Koenigsberger ratios for Hawaiian basalts are typically larger than 10. However for the purposes of this result, only an upper bound on the percentage of induced component is necessary, and these values suffice.

Table 2: Sample magnetisms from a nearby 1971 lava flow.

SN	LOCATION	DESCRIPTION	BSUS	IMAG	RMAG	TMAG	IMAG%
2a	top cracks	dust	359	108	155	263	41
2b	top cracks	dust & chunks	702	211	713	924	22
2c	top cracks	dust & chunks	618	185	222	407	45
3a	mid cracks	dust & chunks	764	229	521	750	31
3b	mid cracks	chunks	117	35	1060	1095	3
3c	mid cracks	chunks	19	6	33	39	15
1	low cracks	chunks	166	50	27	77	64
		Mean	392	118	390	508	32

SN - Sample number
BSUS - Bulk Susceptibility, (μcgs)
IMAG - Induced Magnetization in a 30,000-nT field (μOe)
RMAG - Remanent Magnetization (μOe)
(randomly orientated multiple samples)
TMAG - Total Magnetization if IMAG & and RMAG align (μOe)
IMAG% - Percentage ratio
of induced component to total magnetization

If it is assumed that the remanent component is aligned with the geomagnetic field, then the amplitude of geomagnetic-correlated variations in a gradient from nearby sources can be estimated. In this case, a maximum of 32 percent of the total-field gradient would be dependent upon the geomagnetic field. Only about 0.17 percent of the geomagnetic field contains significant variation. Therefore only 0.05 percent of the gradient magnitude (Table 1FF) would be time dependent. However, regardless of its amplitude, it can be removed because of the correlation with the geomagnetic field.

The total field was measured at each vertex and the centroid of TESSA. The total-field gradient was about 110 nT/m and curvature about 20 nT/m/m. These gradients would have interfered with the experiment except that the remanent components were constant; and the induced components were extremely small and correlated to geomagnetic-field variations. The signals of interest were correlated to neither. However, the gradients still caused noise due to small motions of TESSA (described in Table 1DD and 1EE).

Overall, the close proximity of the magnetic basalts should not have caused problems; the gradients were not too large and they should not have been correlated to volcanomagnetics.

General Procedures

The data acquisition procedure generally was performed once per week by an HVO staff member. The data acquisition program could accumulate up to 6000 samples. At 2 minutes per sample, it would go slightly over 8 days before stopping. A more sophisticated program could have dumped the data to disk periodically and kept on going. But as it turns out, that would have been counterproductive. Because visits had to be made weekly, many unanticipated problems were discovered and fixed before much data loss could occur.

During a routine visit, the data-acquisition program would be stopped for a couple of minutes while the data were dumped to the computer's hard disk and then copied to a 3 1/2" disk. The computer time and true time at the end of the data collection period would be recorded. Then the computer time would be reset. After restarting the data acquisition program, various sub-systems would be checked, the battery voltages recorded, and the Morris temperature recorded (from an independent temperature monitor). If everything was working according to specifications, the TMGS would be left to collect another week's data. The data would then be forwarded to Denver for processing and archival. The step-by-step procedures are given in appendix A.

If a problem was found, the HVO staff could usually fix it. Occasionally, an unusual problem would occur and Denver would be contacted for consultation.

Summary History and Significant Events

Before the Monitoring Period

Well before the monitoring period was to begin, TESSA was crated and shipped to HVO along with Morris and other necessary equipment. A video tape was made showing the packing procedure for TESSA; and a detailed shipping list was drawn up. The shipping list is given in appendix C. On June 3, 1994, the team from Denver arrived and began unpacking and assembling the TMGS.

Before the beginning of the monitoring period, visits were made to potential monitoring sites, the TMGS was assembled and tested, the HVO staff was instructed in the operation of the TMGS, and a few special tests were made.

The special tests included two 14-hour monitoring periods at the monitoring site, two traverses across an empty lava tube, a rotation calibration, mapping the inside of a lava tube with a giant magnet, and a few hours monitoring next to an active lava tube. The traverse data and the rotation calibration are not usable because of the cross-field instability. The results of the other tests will be released in a future publication.

During the Monitoring Period

The monitoring period extended from June 12, 1994 to April 3, 1995. During this time there were a number of special tests performed as well as occurrences or modifications which impacted the data. Detailed field notes of the monitoring period may be found in appendix B. Explanations for periods of data loss are given in appendix G. Following is a semi-chronological listing of significant items and events, which impact the data:

Data Acquisition Programs. - The monitoring period began with a data acquisition program called KMGS9. It is written in Turbo C++ and runs on a 386 lap-top PC. KMGS9 would sample the output from the data-acquisition system at selectable intervals of 0.2, 1, 2, ... 999 seconds.

In an attempt to improve data acquisition and reliability, KMGS9 was replaced with KMGR on November 15. KMGR is similar to KMGS9; the primary difference being that it samples the output from the data-acquisition system continuously (0.2-second intervals), and provides the average value at selectable intervals of 0.2, 1, 2, ... 999 seconds. The interval was always set at 120 seconds.

A quirk in the PC design caused the clock to slow down while KMGR was being run. As a result, the effective sampling interval for data after November 15 is about 120.8 seconds. (A precise value is given in appendix F). The source code for KMGR is given in appendix D.

Rotation Calibrations. - On June 13, October 21, November 17, and March 17, rotation calibrations were performed. These were intended to provide data for rebalancing the TMGS after it had drifted for a time period. Unfortunately, as was discovered afterwards in August of 1995, the cross-field instability was so large as to render the rotation data useless. Nevertheless, the erratic results from the rotation calibrations led to the eventual discovery and documentation of the cross-field instability.

Solar Panels. - On June 23, eight solar panels were installed to keep a charge on the four power batteries. These panels would put out a maximum of 16 to 17 V in bright sunlight and had been designed for applications such as this. Their use removed the necessity to carry four newly charged batteries into the site twice a week. Occasionally during the monitoring period, minor tinkering with the solar panels had to be done for a variety of reasons. But on the balance, they were a good innovation.

Monthly Data Loss. - On July 1, the first of a series of computer program stoppages was encountered. A quirk in the KMGS9 data-acquisition program caused it to halt when the month would change. This seemingly innocuous bug resulted in more data loss than any other difficulty encountered during the experiment. Because the bug was not recognized and fixed until the implementation of KMGR, nearly a week of data was lost at the beginning of every month from July through November.

Power Supply Failure. - On July 8, the power supply (which converts the input from the four 12-V batteries into various voltages used by Morris) failed. It was immediately sent back to Denver where repairs were made. It was re-connected to the TMGS on July 20. During that time, no data could be taken. The cause of the failure was found to be a design maximum input voltage of 15 V; (the use of solar panels had not been anticipated).

Morris Over-Temperature. - From June 23, when the solar panels were installed, until Jul 8, when the Power supply failed, there were numerous occasions when the Morris temperature was found to be extremely high, around 42°C. The over-temperature was caused by the faulty power supply triggering a disconnect of the temperature regulating program. Because of these incidents, a temperature-actuated power-cutoff switch was later installed to protect the electronics.

Dipole Tracking Test. - On November 15 and 16, dipole tracking tests were run to check the effectiveness of dipole mapping from the monitoring site. A large magnet was moved through a set of evenly spaced locations along a surface track that went above TESSA. The dipole mapping algorithm being applied to the tensor produced by the TMGS at each magnet location should have been able to map the magnet locations along the track.

The results showed that directions to the magnet were correct. But there were gross errors in the distances and magnetic moments. A satisfactory explanation for the errors has not yet been found. However, a similar test performed previously in a low gradient location in Arizona returned very good results. The significant differences between the tests were: (in this test) 1) the dc gradients and curvature were much higher; 2) the magnetic latitude was significantly lower; and 3) the track went over the top of TESSA rather than around the sides.

Outside Temperature Sensor Installed. - On December 1, a thermistor was installed for giving the outside air temperature at TESSA's location. The new thermistor was multiplexed with the sensor-4 thermistor at 15-minute intervals. In this way an extra data channel was added without having to add new circuitry to Morris and change the data-acquisition program.

Morris Temperature Destabilized. - During December, the inside temperature of Morris (appendix H) began to slump down toward 33.8°C or below. The slump and associated instability persisted throughout most of the winter with apparent recovery occurring near the beginning of March. Later tests showed that a change of 1.2°C would adversely affect gradient measurements. If the Morris temperature varied, the frequencies imposed on the gradients could not be removed.

Although there was no continuous data channel which recorded the Morris temperature, field notes indicated that these variations were of such amplitude and wavelength as to cause serious interference with the ability to see volcanomagnetics. A satisfactory explanation has not been found. Tests performed after the experiment could not repeat the large temperature swings. Speculations include air pressure or humidity adversely affecting the temperature-holding program; it was designed and tested in a higher altitude and much dryer climate.

Dead Batteries. - The end of January was plagued with a series of battery failures that hung the computer and led to 2 weeks of data loss. The failure was probably due to extended time periods of weak sun and low charge rates from the solar panels.

Changed TESSA's attitude. - On March 17, TESSA was rotated into a new attitude which left sensor 4 on top (fourth position in rotation calibration sequence). The reason for this was to find out how the results are affected by having the common-mode direction radically changed relative to the sensors. Results of this test will be released in a future publication.

Lift Test. - On March 31, TESSA was carefully lifted straight up and then softly repositioned a few times. This test served as an indicator showing whether or not the wild bin changes occurring during the rotation calibrations were also responsible for the unreasonably large steps in readings seen in rotation calibration data. The lift test data also had the same steps indicating that they were likely caused by vibrations or jarring.

Morris-Temperature Variation Test. - On March 31, Morris was repeatedly opened and then reclosed to force large inside temperature variations. This test indicated that, in fact, small gradient errors were correlated to Morris temperature. But it was not controlled to obtain quantitative results.

Total-field values at Sensor Locations. - On April 3 while TESSA was being dismantled, the total-field magnetic values were measured in the actual locations of the RCM sensors and at the centroid of TESSA. These results have been applied in determining the error budget.

After the Monitoring Period

After April 3, 1995, the TMGS was recrated by the HVO staff and shipped to Grand Junction, CO. There, in a magnetically quiet location called Rabbit Valley, TMGS systems were checked and quantitative testing was performed to characterize errors discovered during the monitoring period. After that, the TMGS was shipped back to Denver where additional tests were performed and Morris was modified. Following are the significant events:

Shake-down Tests. - On April 30, the TMGS was re-assembled and all systems were checked and found to be functioning within specifications. Apparently, the systems were all rugged enough to have survived two long trips in airfreight and a 10 month monitoring period in a damp cave. Only minor effects were found, including weathering, loss of a few shims on TESSA due to high humidity, and a strange dislocation of some circuit boards within Morris.

Circuit Thermal Drift Test. - On May 1, the effect of Morris-temperature changes on gradient errors was measured. The Morris temperature was varied in the range of 31°C to 37°C. Then gradient variations were observed after Morris had come to equilibrium at each temperature. The results are recorded in Table 1D.

Erratic Morris-Temperature Check. - On May 1, an attempt was made to discover what might have been responsible for the out-of-spec changes in Morris temperature (Table 1BB) that occurred during the monitoring period. The temperature-holding program and Morris temperature were monitored under various conditions of heat and cold; the temperature variations could not be made to go out of specification nor were any erratic behaviors observed in the program. Another test involved varying battery input voltages over the range induced by the solar panels. No effect was found.

Input Voltage Error Test. - On May 1, the effect of input voltage variations on gradient errors was measured. The battery input voltages were varied in the range of 11 to 17 V. Then gradient variations were observed at several voltage levels and combinations of differing voltage levels among the batteries. The results are recorded in Table 1CC.

Morris Modifications. - During May and June, 1995, A number of improvements were made to Morris including: 1) finding the 250-kHz noise source and replacing the faulty dc-to-dc converter, 2) expanding the data acquisition system to output four additional channels, 3) adding an independent outdoor temperature sensor and data-channel for TESSA, 4) adding an independent Morris-temperature sensor and data channel, 5) adding a 2-axis tilt meter for TESSA, and 6) modifying the KMGR data-acquisition program to accept the four additional channels.

Characterizing the Cross-Field Instability. - During July and August, 1995, a low-noise Helmholtz-coil driver system was developed for testing conditions that may lead to the gross errors encountered during rotation calibrations, traverses, and the lift-test. An exhaustive battery of tests were performed on the RCM magnetometers to discover what was causing the errors.

The results showed conclusively that the problem occurs intrinsically in the core or core material of the magnetometers when a significant (> 7000 nT) cross-field component is present on an axis which is at a high bin number (> 14) and the magnetometer is then jarred. Once jarred, the affected axis will not be able to repeat consistently its previous reading to within less than 100 nT.

The effect, called cross-field instability (Table 1P), is not a result of poor manufacturing, nor of loose or magnetized parts; it is somehow intrinsic to the core material and/or design concept. It must be stressed that cross-field instability does not have any obvious manifestation or apparent effect on data when the magnetometers are operated in a stationary non-vibrating condition. However, it is not clear whether there is a vibration threshold below which no manifestation occurs or whether there is an accumulative effect resulting from long periods of very mild vibration. If there is no threshold, it could have ramifications to the monitoring experiment.

DESCRIPTION OF THE DATA

The data for this experiment may be divided into three groups: primary, secondary, and corroborative.

The primary data are the magnetometer and thermistor channels contained in a series of files produced by the TMGS data acquisition program.

The secondary data include Morris temperature, power-source voltage, and general weather information taken from the field notes (appendix B). These data may become useful during interpretation to indicate whether certain trends or effects could have been related to instrument noise. The Morris temperature and battery voltages have been extracted and compiled in appendixes H and I.

The corroborative data includes such things as: seismic events, tilt events, volcanic events, and geomagnetic observatory data. They can be used to help determine whether any gradient effects observed by the TMGS could be matched with a known volcanic event. These data can be obtained from the Hawaiian Volcano Observatory and the Honolulu Geomagnetic Observatory.

Primary Data Descriptions

The primary data cover the monitoring time period of June 12, 1994 to April 3, 1995 with samples taken at 2-minute intervals. The data are contained in a series of ASCII-formatted files produced by the TMGS data acquisition program (KMGS9 or KMGR), one file having been produced each time the program was run. The files range in length from a few hours to 8 days. A listing of file names, beginning and ending times and dates, and exact sampling intervals is given in appendix F.

During the monitoring period several occasions of data loss occurred. Typically, between data files one or two readings would be lost while data were being transferred to disk. This interval could increase up to a few hours if minor difficulties were encountered or special tests were being made. If a major problem arose, data loss could range from 1 day to 2 weeks. Over a 295-day period, data were collected successfully for 215 days making a 73 percent coverage. A listing of data-loss periods and explanations is given in appendix G.

Each record of primary data contains a sample number (offset) and four groups of data; the groups are ordered to match magnetometer numbers. Each group contains 3 bin numbers, 3 deviation voltages, and 1 sensor-thermistor value. The records are formatted ASCII with each value given in binary two's complement and expressed in hexadecimal. Each file begins with a header record giving beginning time, sample rate, and ending date. An example primary-data file is given in appendix E.

The primary data are simply a collection of four sets of three nearly orthogonal magnetic-field components measured at four different locations in space. The deviation signals contain primarily geomagnetic-field variations. The bin numbers merely indicate constant offsets to be added to the deviations. And the sensor-thermistor signals provide a temperature waveform to correlate and remove from the magnetic fields.

Typical peak-to-peak geomagnetic variations in the deviation signals were: x = 73 nT, y = 69 nT, z = 31 nT, tot = 65 nT. The variations on a given axis (after rotation into the common coordinate system) were usually found to be the same within 1 nT among all four magnetometers.

Because the bin size was 10 times larger than the amplitude of geomagnetic variations, bin changes rarely occurred during the monitoring period. Typical component values (deviation + bin value) for magnetometer 1 were: x = 28,336 nT, y = -423 nT, and z = 15,067 nT, and tot = 32,096 nT. These component values seemed to drift slowly negative a few nanoteslas per month during the monitoring period. Figure 8 shows typical components.

The outside temperature (outside the magnetometer-sensor assemblies) usually stayed in a range from 8°C to 16°C with daily variations of roughly 2°C p2p amplitude. Sensor temperatures were about 9°C higher and had similar-amplitude daily variations. The elevated temperatures of the sensors were due to a slight electrical heat dissipation from the coils being impeded by insulation. The sensor-temperature signals were smooth (high frequencies suppressed) compared to the outside temperature; also the sensor temperatures lagged the outside temperature by a few hours. Presumably, heat capacities within the sensor substrates and assemblies were responsible for both the high frequency suppression and the lag. Figure 9 illustrates typical signals from outside and sensor thermistors.

Figure 8. Graphs showing the x, y, z components of mag 1. Average long-term drift rates are shown. Breaks in data collection are collapsed to zero. Steps occurred during rotation calibrations. The "fuzz" is from daily variations of the GMF.

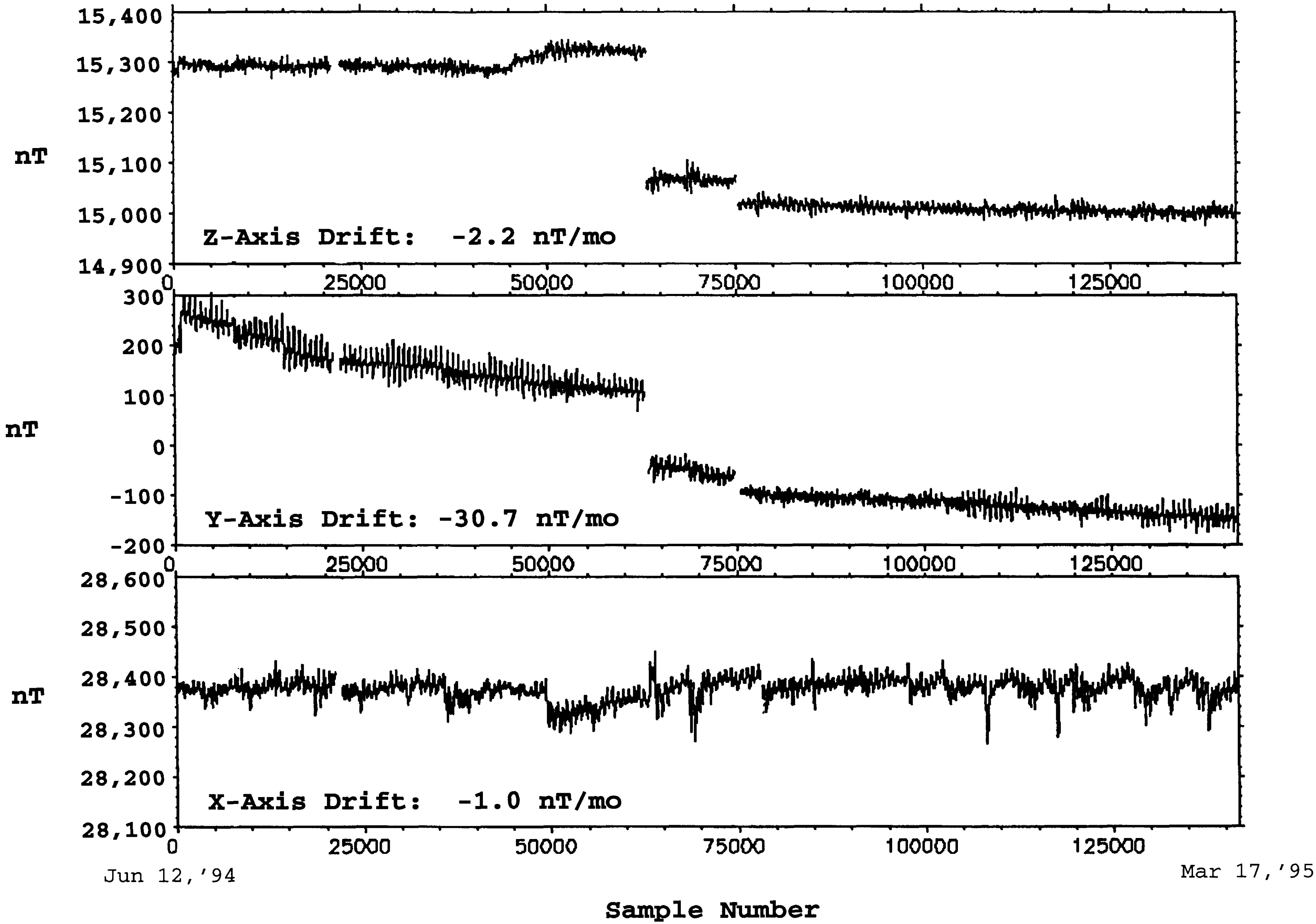
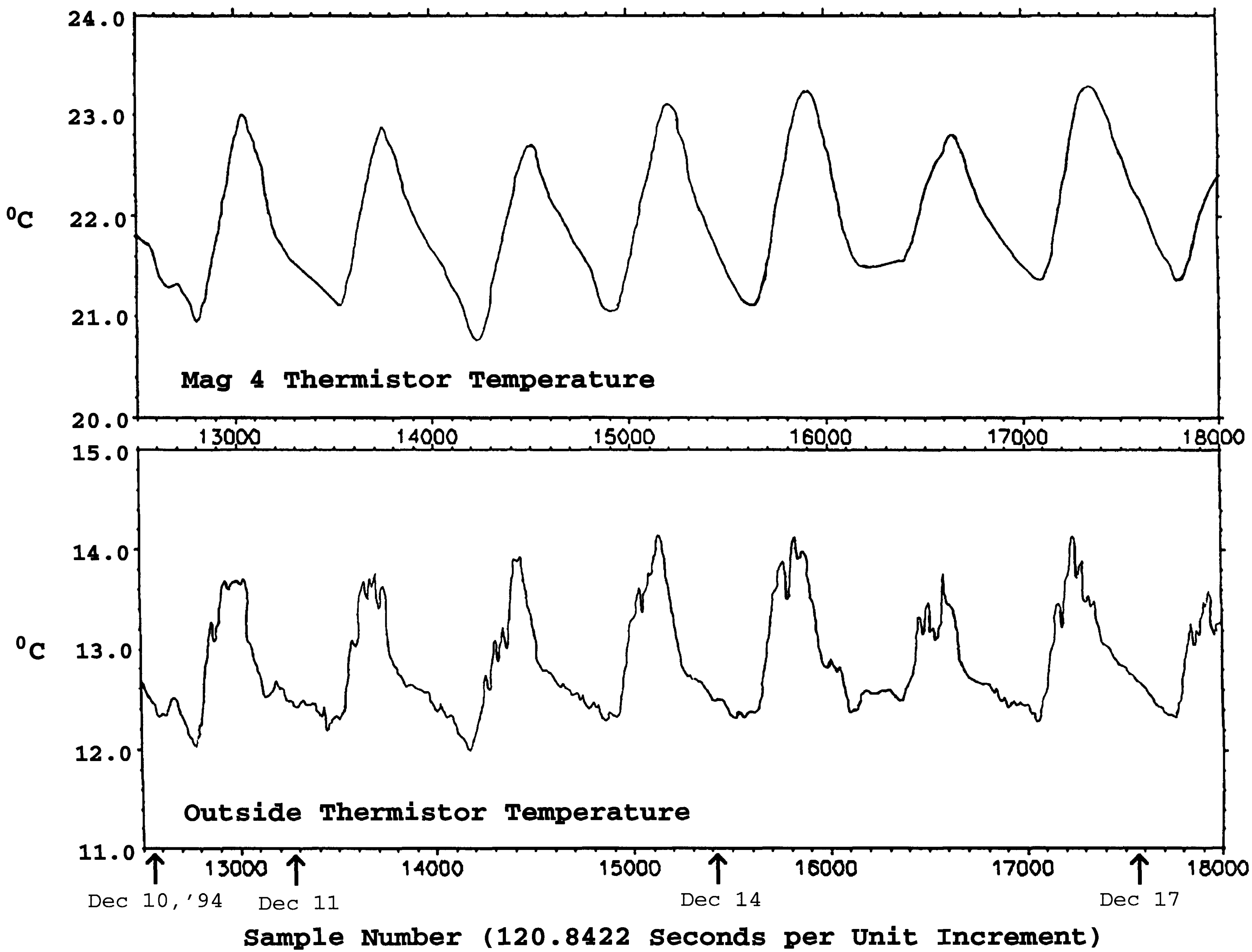


Figure 9. Graphs showing typical temperatures from a sensor thermistor and the outside thermistor.



DATA REDUCTION AND PROCESSING

The purpose of the data reduction and processing is to convert the primary magnetic-field data into a magnetic gradient-tensor function while removing all known errors. As discussed under "Principles of Operation", the gradient tensor is calculated from vector differences in magnetic readings. However, this statement assumes the magnetic readings to be precise! Differencing places stringent requirements on the precision and repeatability of the magnetometers. In a 30,000-nT field, accurately discerning a 0.1-nT/m gradient requires repeatability to better than 1 part in 300,000; a dynamic range of 112.5 dB would barely suffice. Therefore, great care must be exercised in producing an appropriate set of reduction and processing procedures.

Reduction Procedures

The RCM is not a quantum device; its circuitry is replete with analog devices, amplifiers, gains, offsets, coils, thermal dependencies, and the like; none of which behave with quantized precision. Although the RCM's components are very good, their coefficients differ slightly from the ideal and, in some cases, may drift. As a result, they must be calibrated with extreme care in order to maintain the precise tracking needed for gradient measurements. Any imprecision in the tracking will result in geomagnetic field, thermal, or other waveforms leaking into the gradient. If the data reduction is successful in plugging all the leaks, only the intrinsic noise levels of the device will remain; for the RCM, these are quite small.

There have been three data-reduction procedures developed for the TMGS, each with improved results over the previous. The first was a direct calibration method, the second an iterative calibration, and the third a frequency-domain coherence filter. All of them were designed to remove effects of the following:

1) Sensor, conversion-coefficient errors:
   - Bin size error,
   - Deviation-coefficient error,
   - Zero-voltage error,
2) Sensor, thermal dependencies,
3) Sensor, design-geometry errors:
   - Bucking-coil interference,
   - Spatial blurring,
   - Inorthogonality,
4) Platform (TESSA) attitude transformation errors,
5) Platform (TESSA) thermal dependencies.

Direct Calibration Method

The first data-reduction procedure involved writing a conversion equation which utilized scalar, vector, and tensor coefficients to give the precise magnetic field vector as a function of bin number, deviation signal, and temperature. Then, those coefficients were measured during an extended series of tests done before the Hawaii monitoring period. (This research, which has not yet been published, formed the basis for much of our understanding of the RCM responses).

This method has the advantage of being able to establish a general set of coefficients for a given magnetometer, which will then work in all magnetic-fields and temperatures. Data reduction simply involves application of the data and coefficients to the conversion equation.

However, with the available facilities, the coefficients could not be measured accurately enough. When applied to the monitoring data, leaking waveforms remained at the 2 nT/m rms level. Figure 10 is an example of monitoring data reduced by the direct calibration method.

Iterative Calibration Method

The second data-reduction procedure used the same basic equation as the first. However, the coefficients were calculated from the monitoring data itself rather than being measured independently. The calculation used an iterative method to select trial coefficient values, put them into the conversion equation, and then observe the variance. The coefficients selected would be those which resulted in the least variance.

This method has the advantage that it is generally applicable to any set of magnetometers and does not require precise initial values for the coefficients. It utilizes the built-in precision of the magnetometer to determine its own coefficients. It can handle certain types of non-linear relationships. Several disadvantages are: iteration is time consuming, large parameter spaces (of the conversion equation) may have many incorrect wells, frequencies are weighted unevenly, and phase displacements cannot be handled.

When applied to the monitoring data, leaking waveforms were reduced significantly with gradient noise levels better than 0.6 nT/m rms. Figure 11 is an example of monitoring data reduced by the iterative calibration method.

Coherence Filtering Method

The third data-reduction procedure uses a linear multiple input/output system (Bendat and Piersol, 1986) operating in the frequency domain to remove all gradient waveforms that are coherent with the geomagnetic field and the temperature. This method does not use (directly) the conversion equation and therefore is not bound by those constraints; it can find and remove signal paths which may not have been accounted-for in the conversion equation.

Figure 10. Graphs showing the x, y, and z components of gradient data reduced by the DIRECT CALIBRATION METHOD. The gradient is in the direction from mag 4 to mag 1. A constant has been removed from each graph.

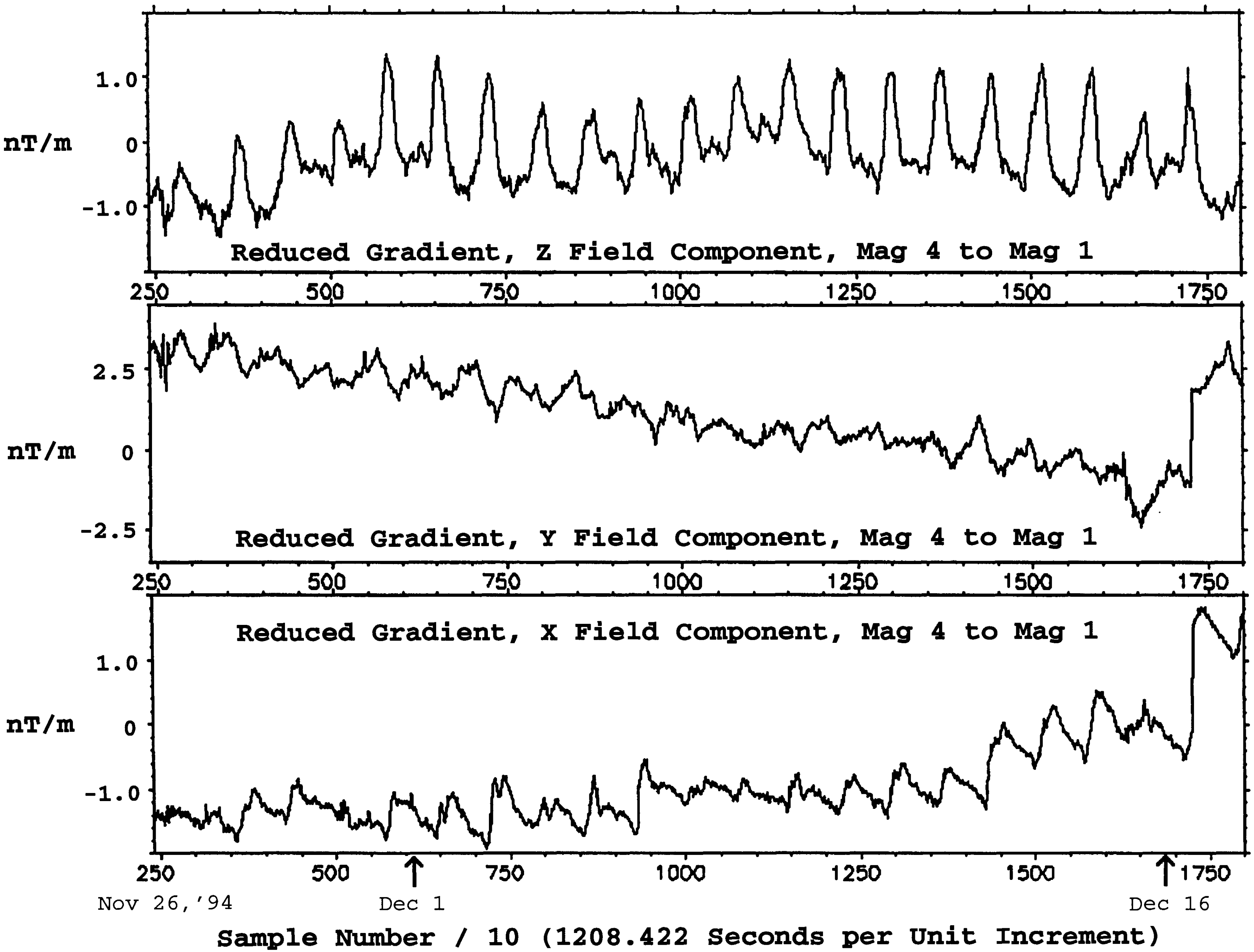
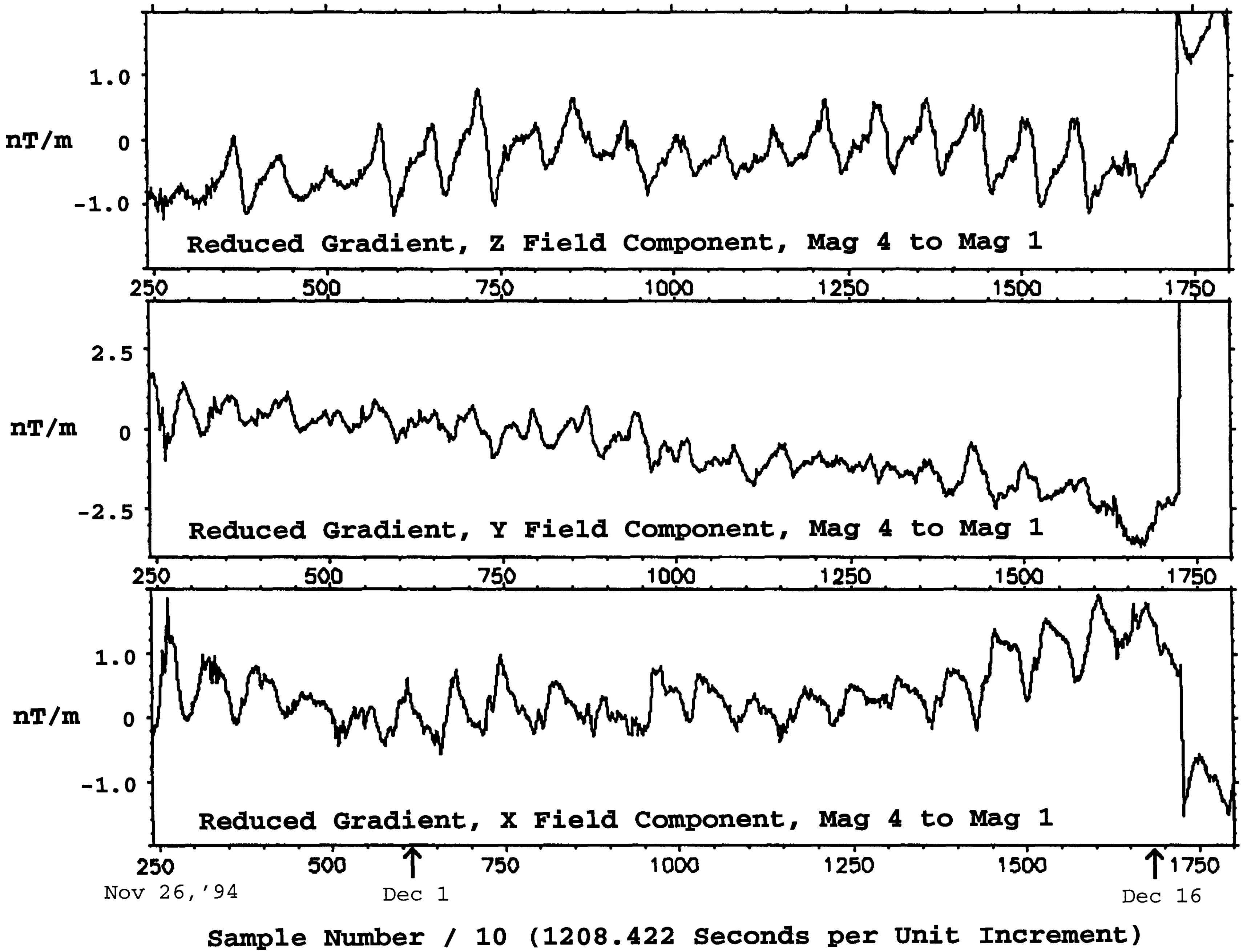


Figure 11. Graphs showing the x, y, and z components of gradient data reduced by the ITERATIVE CALIBRATION METHOD. The gradient is in the direction from mag 4 to mag 1. A constant has been removed from each graph.



The coherence filter shares most of the advantages of the iterative calibration and has none of the disadvantages. It does not, however, remove nonlinearities. The coherence filter is linear. It finds implicitly all coefficients in the conversion equation which are constant and appear in terms linear with respect to geomagnetic field and temperature. It also transfers properly the effects of causal filters such as the insulation and heat capacity of the magnetometer sensors. These kinds of filters can produce signal delays between the sensor-thermistor values and the effects of thermal variations deep in the sensor cores. Because of many bin number effects and dependencies, the filter is compromised if bin numbers change in the data stream.

When applied to the monitoring data, gradient noise levels were better than 0.25 nT/m rms in two of the three field-component directions. Figures 12, 13, and 14 show an example of this result. The figures show the gradient of each of the three magnetic field components (x, y, z) along the direction defined by the line from magnetometer 4 to magnetometer 1 (the field components have been rotated into a geographic reference frame but the gradient direction has not).

What is causing the residual longer wavelength signal in the uncorrelated graphs of x and z is not entirely clear. However, a likely cause is the substantial variation of the Morris temperature which occurred during this time period (see appendix H). The remaining noise should be composed of the unremovable noises listed in Table 1.

For comparison purposes, the geomagnetic-field variations have been included in figure 15, which covers the same time period as figures 10-14. It is interesting to compare the correlated z component of gradient in figure 14 with the GMF variations in figure 15 and the temperatures in figure 9; apparently, the z component contains a thermal dependency much stronger than the leaking geomagnetic field.

Operation of the Coherence Filter

This coherence filter operates on the assumption that a volcanomagnetic event will produce a gradient that is transient and incoherent with respect to geomagnetic variations. It removes everything that is coherent leaving only noise and incoherent events.

The filter is applied in two stages. In the first stage, two magnetometers are chosen. Then a representative sample function is taken from the data stream to produce the following vector of 6 input functions: the 3 axes of the geomagnetic field from one of the magnetometers, the 2 magnetometer temperatures, and the outside temperature. The unfiltered difference between one component of the two magnetometers is given as the output function. The input and output functions are windowed (Harris, 1976) and stacked in the frequency domain. The filter algorithm then solves the system of expected values and returns a vector of

Figure 12. Graphs showing the x component of raw gradient data separated by the COHERENCE-FILTERING CALLIBRATION METHOD into components correlated and uncorrelated to geomagnetic-field variations. A linear trend has been removed from each graph.

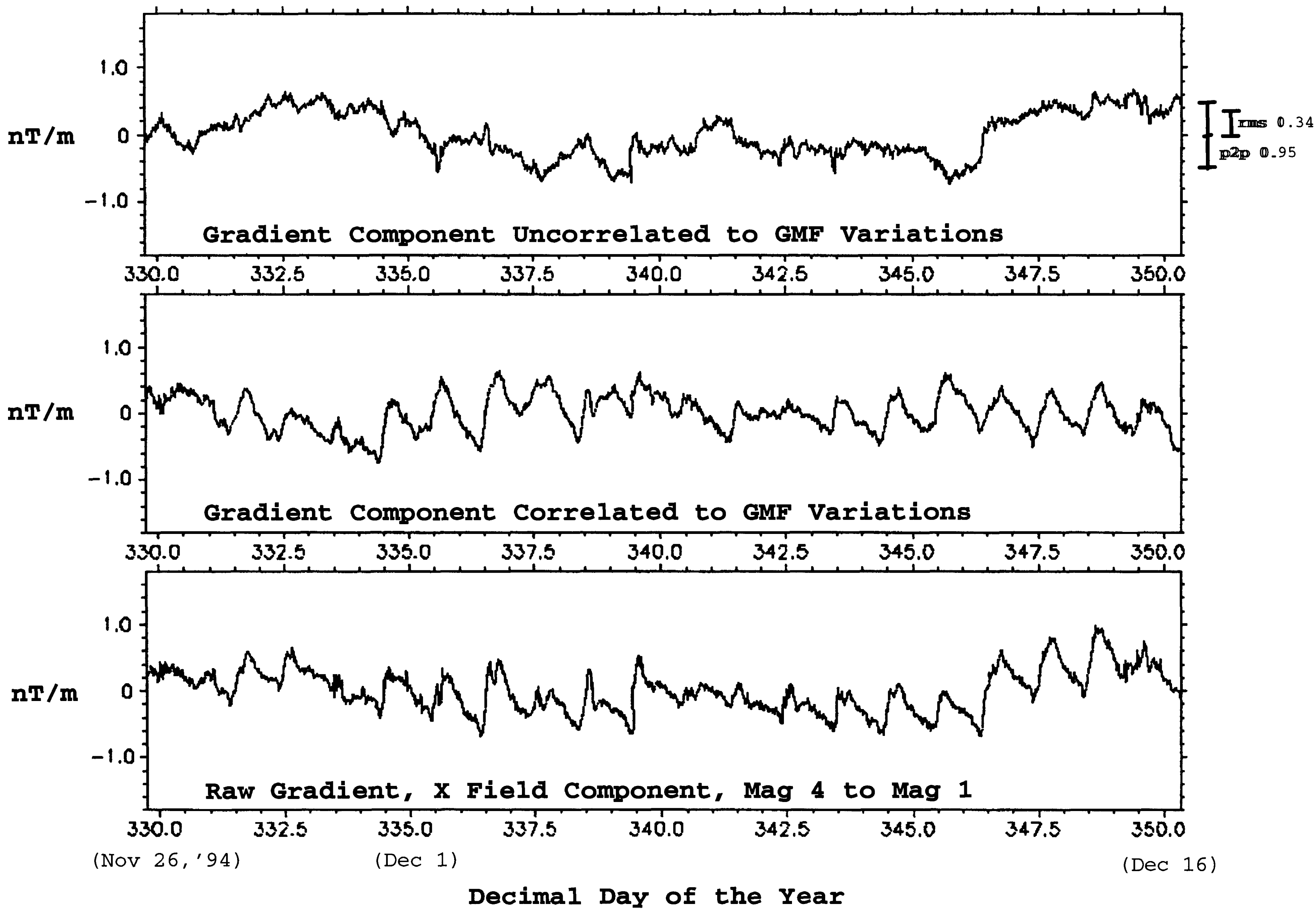


Figure 13. Graphs showing the y component of raw gradient data separated by the COHERENCE-FILTERING CALIBRATION METHOD into components correlated and uncorrelated to geomagnetic-field variations. A linear trend has been removed from each graph.

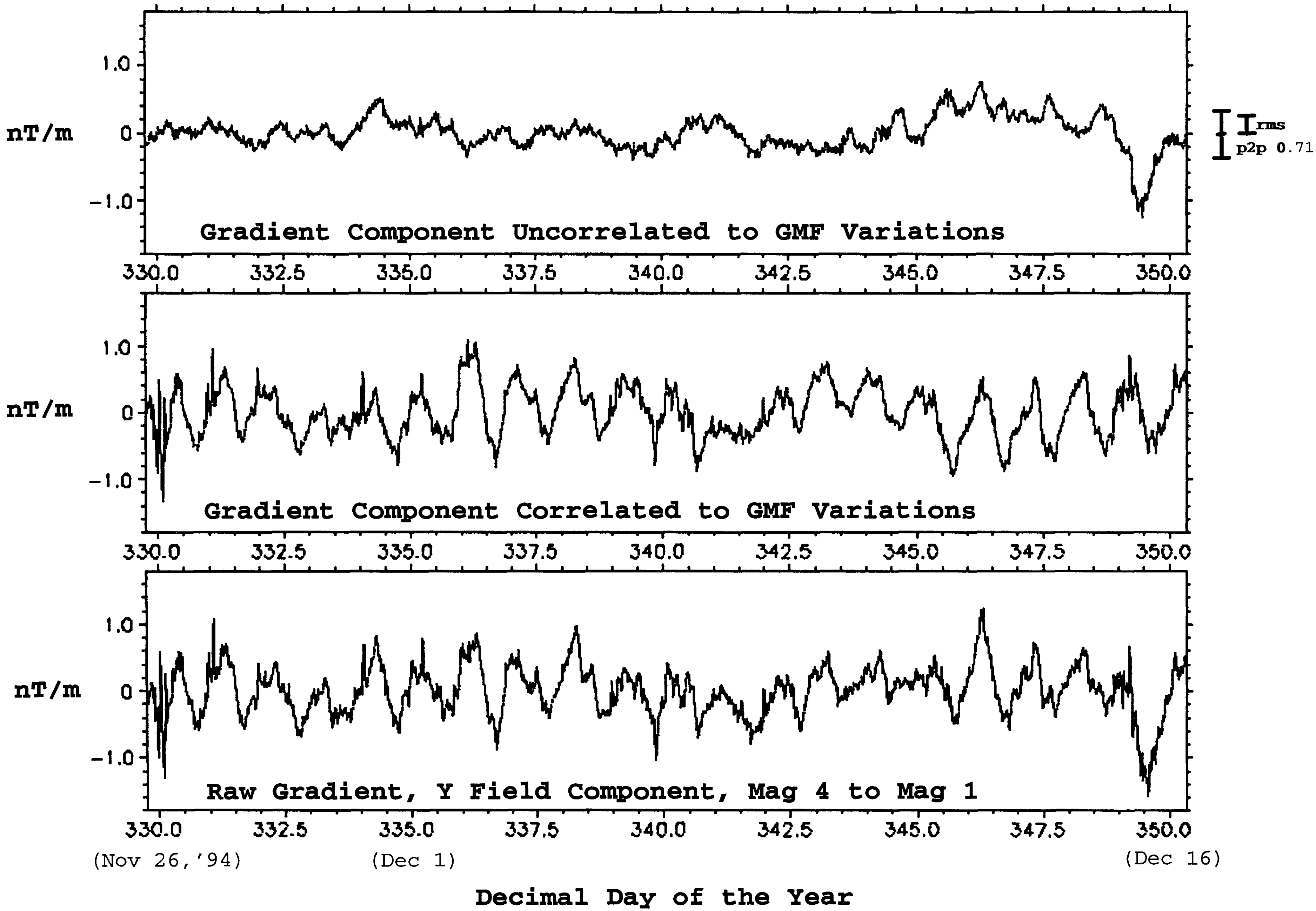


Figure 14. Graphs showing the z component of raw gradient data separated by the COHERENCE-FILTERING CALIBRATION METHOD into components correlated and uncorrelated to geomagnetic-field variations. A linear trend has been removed from each graph.

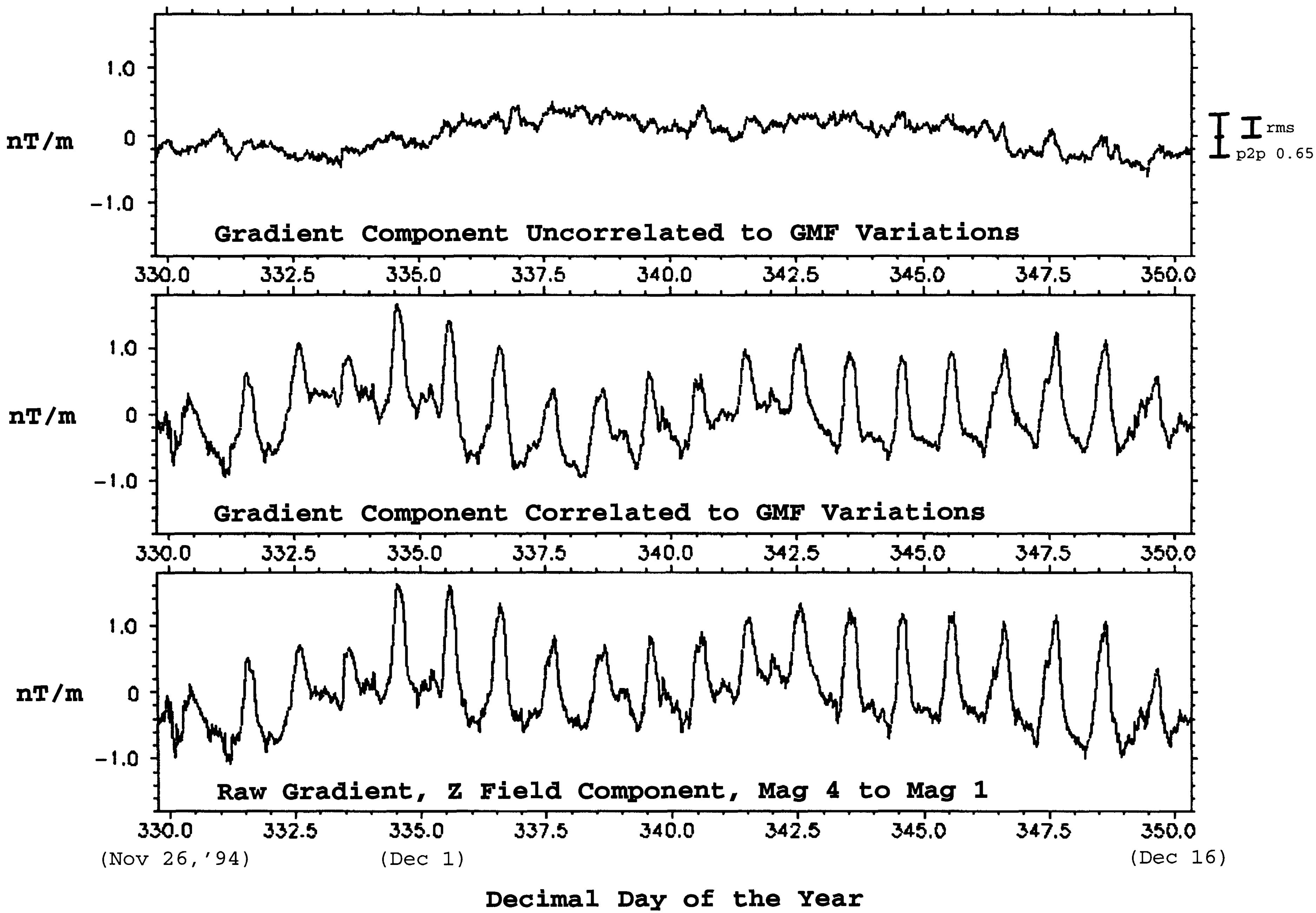
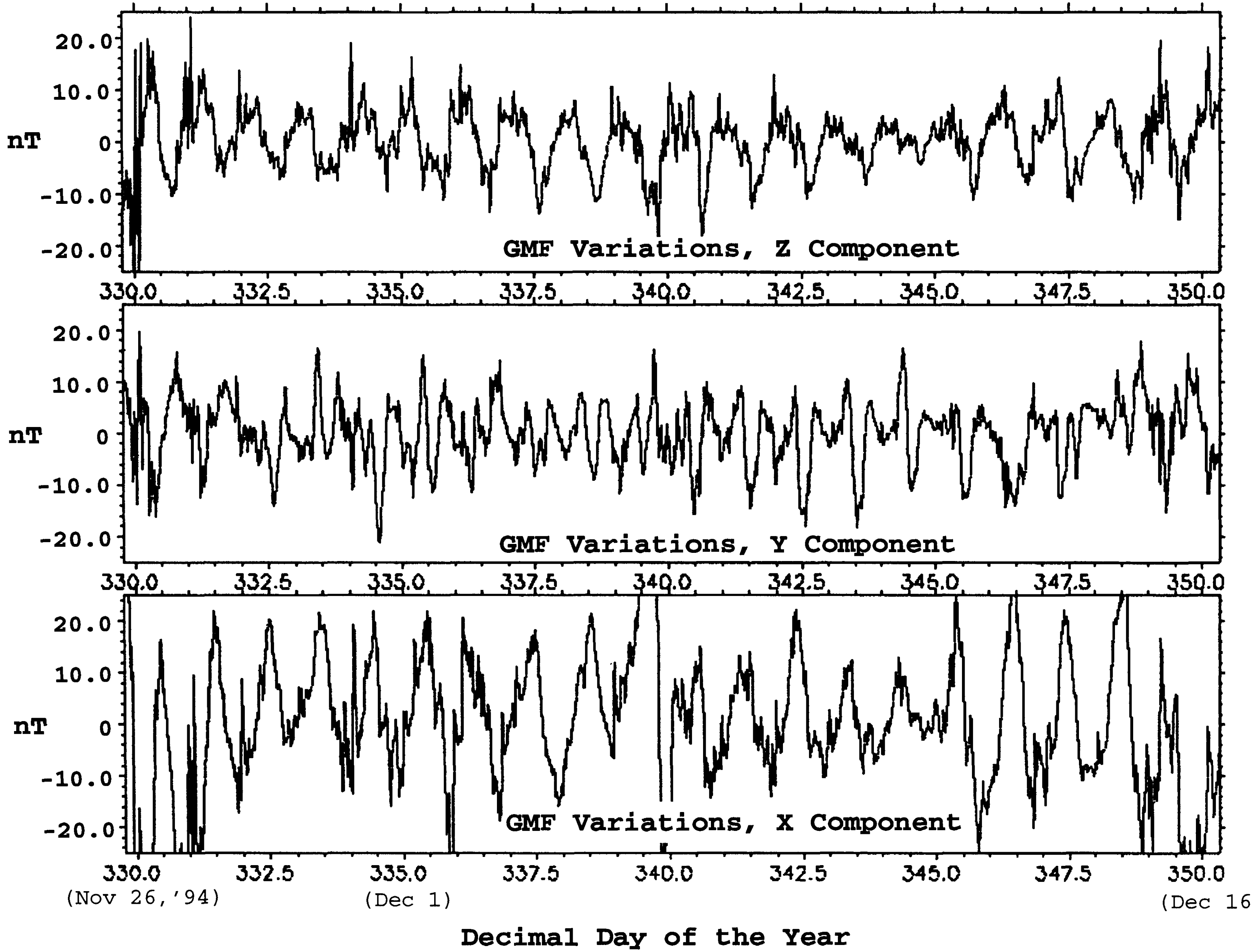


Figure 15. Graphs showing the x, y, and z components of geomagnetic-field (GMF) variations recorded by mag 1. A linear trend has been removed from each graph.



six transfer functions which relate the input functions to the coherent part of the output function.

In the second stage, the same input and output functions are again chosen but this time the entire stream is used. The input functions vector is dotted with the transfer function vector to produce a correlated output function. Finally, The correlated output function is subtracted from original output function to produce the filtered function.

Processing Procedures

The processing involved a series of steps that simultaneously reduced and converted the primary data into the magnetic tensor gradient function. The basic conversion steps are as follows:

1) Convert the bin numbers and deviation voltages to magnetic-field component values and calibrate,
2) Rotate the components into a common geographic frame of reference,
3) Find component differences along tetrahedral-edge vectors,
4) Create gradient values by dividing the component differences by the sensor separation distance,
5) Rotate each gradient vector into the tensor coordinate system.

The actual processing, which incorporated reduction, was more complicated. Reduction techniques were applied at several steps along the way and extensive data preparation was necessary. Following is a brief description of the process:

1) The data were broken into three groups with each group being handled separately. The groups were chosen because of natural changes in the data (such as changing data acquisition programs) and because of long-term drift in the magnetometers.

2) All discontinuities, steps, and spikes, were adjusted out and removed from the deviation signals and temperatures. For data after November, the outside temperature was demultiplexed from the sensor-4 thermistor channel. For data before November, an artificial outside temperature channel was created by producing a transfer function from the post-November temperature data.

3) Data gaps in each group were filled and the ends extended with dummy data in order to keep the ends of transformation windows from encountering discontinuities.

4) Using the coherence filter reduction, coherent waveforms were removed from among the deviation signals in all four magnetometers. Magnetometer 4 was selected as the geomagnetic reference (supplies the three geomagnetic input functions) because it was the quietest.

5) All of the deviation signals were low-pass filtered with a non-causal 4-pole Butterworth (Hamming, 1977) characteristic (24 dB/octave) at a 1-hour cutoff wavelength.

6) All of the deviation signals were converted to magnetic values and added to their corresponding bin values to obtain magnetic-component values.

7) The components from magnetometers 2, 3, and 4 were rotated into the geographic reference frame common with No. 1 (x - north, y - east, z - down).

8) Coherent waveforms were again removed from among the components.

9) The components were differenced and divided by the distance between the sensors to obtain gradients along the tetrahedral edges.

10) Four magnetic gradient tensors were created (in the geographic coordinate system) using the edge gradients. There are six independently measured edge gradients associated with any one of the four faces of TESSA. Only five of these gradients are needed to produce a complete tensor. Therefore, four tensors may be produced from slightly different data.

11) Using the fact that all four tensors must be identical, a final tensor function was produced from the coherent parts of the four.

12) All of the sections that had more than 30 minutes of dummy data were zeroed and identified as such.

13) The magnetic tensor gradient function is the final product of this process.

The tensor is oriented in a geographic reference frame where x is approximately magnetic north, y is east, and z is down. The following illustrates the magnetic tensor gradient function:

$$\{G\} = \begin{vmatrix} Gxx & Gxy & Gxz \\ Gyx & Gyy & Gyz \\ Gzx & Gzy & Gzz \end{vmatrix}$$

Where: Gij are functions of time
i is the field direction x, y, or z
j is the gradient direction x, y, or z
Gij = Gji
Gxx + Gyy + Gzz = 0

RESULTS

Most objectives of this research have been met. The prototype TMGS was built, tested, and made serviceable. It was found to be a reliable instrument capable of long term monitoring.

Basic calibration coefficients had been measured for use in the magnetometer conversion equations. However, it was found that these coefficients were not accurate enough for the gradiometer application. Instead, by the use of coherence filtering, an equivalent set of coefficients can be found which are accurate enough for gradient measurements. This technique, however, can only be implemented when long periods of data have been accumulated without having moved the TMGS sensor.

A complete noise analysis was made (Table 1) showing a break down of possible noise sources. Most of this analysis is based on special tests conducted independently of the monitoring data. Therefore, disagreements between the noise analysis and actual noise content of the monitoring data are expected; and they indicate the presence of an unaccounted for noise or a different-than-expected value of an accounted-for noise.

All large effects of leaking geomagnetic and thermal variations have been successfully removed. There is, however, a suspicion that second order or cross product (non-linear) noise may still be present in the gradient data. Other variations dependent on Morris temperature and input voltage are also suspected. Neither of these independent variables were measured during the monitoring period. However, the TMGS has now been modified to measure the Morris temperature along with the data stream.

It was found that after extensive data reduction procedures, the TMGS can be stabilized to within about 0.2 nT/m rms for periods from a few hours to a few weeks. Longer wavelengths were removed during data reduction; shorter wavelengths were filtered out. If the longer wavelengths are not removed, an instrument related long-term drift of several nanoteslas-per-meter per month can be observed. Instrument noise in the shorter wavelengths during this experiment could reach 0.3 nT/m rms due to a malfunctioning circuit. That problem has been fixed and it is expected that in future experiments higher frequencies will not need to be filtered out. It is suspected that the bad circuit also contributed to noise smearing throughout the spectrum due to an unfilterable aliasing phenomenon.

The deployability of the prototype TMGS should be rated as difficult. The primary cause for difficulty is the need for a sheltered environment. During this experiment it was kept in a lava tube, out of the sun, wind, and rain and with moderated temperatures. An alternative would be to construct an insulated enclosure. The instrument would not do well if TESSA was exposed to the elements. A second difficulty arises from the weight, size, and number of pieces of equipment that must be set up. It has a fairly hefty power requirement needing several large deep-cycle batteries replenished once or twice weekly. Finally, the learning curve is fairly steep for operating and servicing the equipment. Nevertheless one should remember that this is a prototype, the design is experimental, and operator comfort is secondary.

The reliability of the instrument should be rated as moderate to good. During the first half of the monitoring period, several periods of data loss occurred because of a bad power supply and a programming bug that had not been anticipated. Both were then fixed and did not manifest during the second half of the period. The only other significant data loss occurred when the batteries were allowed to be drained. However, this would not have been as significant if the program had been designed to make periodic dumps to disk. Future implementations of the program will perform this function. There were no significant failures of the main electronics in Morris; occasionally a magnetometer had to be reset. The Morris temperature fluctuated out of specification for inexplicable reasons but only once with system failure resulting. The condition that led to system failure has been fixed.

The serviceability would be good if not for the power consumption. The system had to be visited once per week to remove data and restart the program. If a longer term power source was available, the program could be changed to take data indefinitely.

The hoped-for observation of a volcanomagnetic event probably did not occur (one may be visible in the data but not clearly above noise levels). A combination of factors precluded it. The TMGS was set up in a location that was 5 km from the nearest likely event and the rms noise levels turned out to be 0.2 nT/m. It was expected that an event could reach 0.1 nT/m. So the instrument noise would have had to be around 0.07 nT/m rms, 9 dB quieter than what was attained.

CONCLUSIONS

A very useful result of this experiment has been the development of a data reduction procedure for a TMG system. Most of the issues addressed by this procedure are generally applicable to any TMG data where differencing is the basis of operation.

The suitability of this prototype TMGS for monitoring volcanomagnetics is marginal to unsuitable. The primary reason is lack of sufficient sensitivity; a secondary reason is deployment difficulty. However, it was intended as a learning machine for proof of principle, not a workhorse. It was known before deployment that it might be possible to get noise levels down to 0.1 nT/m and a volcanomagnetic event might get up to that level. Finding a meeting of the two was a chance that was taken. The actual data indicate that basic noise levels were around 0.2 nT/m rms.

The idea of using a TMG system for measuring volcanomagnetics is an excellent one that is now coming of age. Recent improvements (since the designing of the prototype) in vector magnetometer sensitivities and the advent of the high-temperature SQUID have opened new possibilities for selection of basic sensor elements. This experiment, itself, has shed light on the instrument design which can and should be applied to a next generation.

REFERENCES CITED

Acuna, M.H., Scearce, C.S., Seek, J.B., and Scheifele, J., 1978, The MAGSAT vector magnetometer - A precision fluxgate magnetometer for the measurement of the geomagnetic field: Greenbelt, MD, National Aeronautics and Space Administration Technical Memorandum 79656, 18 p.

Bendat, J.S. and Piersol, A.G., 1986, Random data, analysis and measurement procedures: New York, NY, John Wiley & Sons, Inc, p. 226-249.

Hamming, R.W., 1977, Digital filters: Englewood Cliffs, N.J., Prentice-Hall, Inc., p. 3, 189, & 193.

Harris, F.J., 1976, Windows, harmonic analysis, and the discrete Fourier transform: San Diego, CA, Department of the Navy, Undersea Surveillance Department, NUC TP 532, 69 p.

Narod, B.B., 1987, Ring core fluxgate magnetometers for use as observatory variometers [abs.]: International Union of Geodesy and Geophysics 19th General Assembly, Abstracts, v. 2, no. GA5.3-3, p. 673.

Nelson, J.B., 1988, Calculation of the magnetic gradient tensor from total field gradient measurements and it application to geophysical interpretation: Geophysics, v. 53, no. 7, p. 957-966.

Pedersen, L.B., Rasmussen, T.M., 1990, The gradient tensor of potential field anomalies: Some implications on data collection and data processing of maps: Geophysics, v. 55, no. 12, p. 1558-1566, 6 figs.

Wynn, W.M., Frahm, C.P., Carroll, P.J., Clark, R.H., Wellhoner, J., Wynn, M.J., 1975, Advanced superconducting gradiometer/magnetometer arrays and a novel signal processing technique: IEEE Transactions on Magnetics, v. MAG-11, no. 2, p. 701-707.

Zlotnicki, J., and Le Mouel, J.L., 1988, Volcanomagnetic effects observed on Piton de la Fournaise volcano (Reunion Island): 1985-1987: Journal of Geophysical Research, v. 93, no. B8, p. 9157-9171.

ACKNOWLEDGEMENTS

The authors extend appreciation to the following people who devoted their time and resources to help in this research:

Thomas G. Hildenbrand, U.S. Geological Survey, Menlo Park, CA, for envisioning the monitoring experiment and making it a project;

James P. Kauahikaua, U.S. Geological Survey, Hawaiian Volcano Observatory, for coordinating activities, making arrangements through HVO, devoting time and resources, and supplying expertise;

Donald W. McNair, U.S. Geological Survey, Denver CO, for building TESSA;

Julius Likler, U.S. Geological Survey, Denver CO, for precision machine work to interface the magnetometers;

Victor F. Labson, U.S. Geological Survey, Denver CO, for providing scientific consultation and wisdom;

Carl Stoddard, U.S. Geological Survey, Denver CO, for dedicated field assistance during testing and deployment;

Donald D. Snyder, RUST Geotech, Inc., Grand Junction, CO, for providing technical consultation during development.

APPENDIXES A-J

Appendixes of various auxiliary descriptions, data and results following.

APPENDIX A. FIELD PROCEDURE INSTRUCTIONS

TMGS MAINTENANCE

1.0 NORMAL PROCEDURE,

VERSION 1.0, 13JUN94
VERSION 1.1, 20JUN94

(Assuming battery rotation rather than solar panels)
(Assuming 1 week servicing intervals)

1.1 CARRY TO THE SITE:

8 96493 deep cycle 90 Ah batteries
20 Jumper wires for interchanging and paralleling batteries
1 3 1/2" disc
1 Voltmeter (with flee clips and needle probes)
1 Standard sized screwdriver
1 9-V transistor battery
1 Flashlight

1.2 UPON ARRIVAL AT THE SITE: (THIS PROCEDURE IS VERY CRITICAL. IF ANY GOOF-UPS OCCUR, YOU COULD LOOSE A WEEK OF DATA)

Remove the tarp
Check the Morris TEMP (tn) by flipping the switch on the electronic thermistor box. It should show 34.8 to 35.2
Open the computer lid
Light the computer screen by hitting the CNTRL key (if it does not light, adjust the contrast & brightness)
Hit the END key
Immediately after, hit the S key
After up to 4 minutes the words "saving data" should appear
Wait a couple more minutes for the save to complete and screen to clear

1.3 COPY THE CURRENT DATA FILE ONTO THE 3 1/2" DISK:

Copy to the A: drive using copy/v (v=verify)
One disk can hold 2 weeks of data
Label and stow the 3 1/2" disk
Be sure to set the write lock after copying

1.4 DELETE THE PREVIOUS WEEK'S (NOT THE CURRENT) DATA FILE OFF THE C: DRIVE (ASSUMING THE DATA QUALITY HAS BEEN CONFIRMED):

There is enough space on the hard drive to keep up to about 10 weeks of data. If you choose to keep more than 1 week of data on the hard disk, be very careful about approaching the disk capacity. If there isn't enough space left, an entire week's data could be lost. Each week of data takes about 0.6 Mb.

1.5 EXAMINE THE CURRENT WEEK'S DATA USING KDISP6 [filename]:

Select a MAG using 1,2,3,4 keys
Select an axis or TEMP using x,y,z,t keys
Select a screen (500 data samples per screen) using right or left arrows
Look for irregularities that may signify trouble

1.6 ROTATE IN THE EIGHT CHARGED BATTERIES. FOR THIS PROCEDURE, KEEP IN MIND THE FOLLOWING:

Batteries are paired into 4 groups of 2 in parallel
The batteries connected to the thermoelectric-device (TED) subsystem and the COMPUTER power supply may be disconnected momentarily without disrupting the system
The batteries supplying the main digital system (12/24 V) MUST BE TRANSFERRED WITHOUT DISRUPTING ANY POWER. If a power disruption occurs, a Morris system restart must be initiated after finishing the battery transfer. (see Morris restart).

1.7 DO A ROTATION CALIBRATION ABOUT ONCE PER MONTH:

See rotation calibration for a description
Double check the Morris TEMP before the rotation calibration

1.8 START THE DATA ACQUISITION PROGRAM:

Set the computer directory to c:\rcm\mile8mon
Run KMGS9 (not KMGS8)
File: MMMDDm8m (example: jun13m8m). Use today's date
Sample interval: 99 (a code# meaning 120 seconds)
Comment: Monitor in lava tube at 8-mile mark, HVO, HI
Hit U (update) a couple of times and examine the MAG and thermistor values. If anything looks fishy, check for proper connections by applying the disconnect/reconnect test on the MAG and thermistor in question.
Hit F (fillram) once. Observe the screen for about 4 minutes until you have seen at least 1 or 2 samples taken. Check for irregularities or non-functionality.
When satisfied that the program is running properly, lower the computer lid

1.9 CHECK THE MORRIS TEMP (TN) AGAIN:

Turn on the electronic thermistor box
It should show 34.8 to 35.2

If the temperature is outside this range, something is wrong, see troubleshooting
Turn off the electronic thermistor box when done

1.10 COVER THE SYSTEM WITH A TARP AND RETURN TO THE LAB WITH THE EIGHT DISCHARGED BATTERIES

1.11 AT HVO:

Note how far discharged the batteries are. It may be possible to reduce the number of batteries required next trip out.
Put the batteries on charge
Load the new data onto a PC and FTP (ASCII) it to a directory on TAKO or MUSETTE
Set protections so that it can be accessed by RBRACKEN
Send Email to rbracken@musette.cr.usgs.gov saying where the data is located and listing the new data file name(s) Also, describe any irregularities (especially in the Morris TEMP)
Wait for return Email confirming the data quality before erasing the original from the C: drive on the data acquisition computer
Keep the data on the 3 1/2" disk for eventual return to Denver

2.0 ROTATION CALIBRATION

VERSION 1.0, 21JUN94

THE ROTATION CALIBRATION SHOULD BE PERFORMED ABOUT ONCE PER MONTH AS A ROUTINE. IT SHOULD BE DONE DURING THE NORMAL PROCEDURE AS DESCRIBED ABOVE (SEE NORMAL PROCEDURE).

2.1 START THE DATA ACQUISITION PROGRAM:

Make sure all people, tools, etc have been removed from the vicinity of the tetrahedron
Set the computer directory to c:\rcm\mile8mon
Run KMGS9
File: MMMDDr1 (example: jun13r1). Use today's date
Sample interval: hit return (a code meaning 0.2 seconds)
Comment: Rotation cal position 1 (8-mile mark, HVO, HI)
Hit U (update) a couple of times and examine the MAG and thermistor values. If anything looks fishy, check for proper connections by applying the disconnect/reconnect test on the MAG and thermistor in question.
Hit F (fillram) once. At this high sample rate, only the sample# will update; the other values on the screen will not change
After 30 seconds (150 samples), hit END, and hit S. The screen will say saving data and shortly the prompt will appear.

2.2 ROTATE TESSA TO POSITION 2 (THE POSITION NUMBER IS EQUAL TO THE TOP MAG NUMBER)

With at least two people, go down into the lava tube
On TESSA, find MAG 2. This MAG is to be rotated to the top. MAG numbers are displayed in large numerals (e.g. 2) on the back of each MAG cover box and in small numerals (e.g. V2) on the top front right corner of each vertex plate.
The rotation axis runs through the centroid of the tetrahedron and is perpendicular to the line between mag2 and mag1
Once the rotation axis has been found, it will be obvious which two of the six handles are to be used for this rotation
Rotate the tetrahedron 180° about the rotation axis using one person on each end of the rotation axis. If a third person is available, they may be very helpful in routing the cables. WARNING: DO NOT ALLOW ANY OF THE MAG, MAG BOX, OR VERTEX PLATE TO TOUCH ANY SURFACE DURING THE ROTATION PROCEDURE. THIS PROCEDURE CALLS FOR GREAT UPPER BODY AND ARM STRENGTH AS WELL AS CAUTION AND FORETHOUGHT.

Helpful suggestions for smoothing the rotation:
- Both people should agree ahead of time on the rotation direction
- The person with the vertical handle should lift it up only a small amount. But the person with the horizontal handle should lift it up a large amount until the rotation axis is nearly horizontal. ROTATION SHOULD NOT PROCEED UNTIL THE ROTATION AXIS IS HORIZONTAL.
- Once the rotation axis is horizontal, rotate the tetrahedron in the agreed direction one half of a turn until the vertical handle is again vertical. Then stop the rotation.
- After the rotation has been stopped, the person with the vertical handle should continue holding it up while the person with the horizontal handle should lower it until the new set of three legs is coming close to the base platform
- Carefully set the tetrahedron on the base platform making certain that the weight is fully on the tetrahedron legs and NOT on the vertex plates, MAG boxes, or calibration standards. Also be sure that the front leg is not sitting on the unpainted scope mounting plate.

After setting the tetrahedron down, press the calibration blocks against the calibration standards and align the red lines on the left calibration block and standard
When making horizontal adjustments to the position of the tetrahedron, be very careful not to put horizontal forces on the base platform. Rather, apply some kind of counterforce between the upper base platform and the

tetrahedron. To check whether the calibration blocks are contacting the calibration standards, shine a flashlight through the interface. If any part of the interface is blocking the light, then proper contact has been made.

Inspect underneath the tetrahedron to be sure none of the wires or MAG boxes are contacting the base platform

Inspect the two levels to make sure that nothing was accidentally bumped out of true

2.3 REPEAT 2.1 AND 2.2 ABOVE ADDING 1 TO EACH MAG NUMBER (E.G. MAG 2 BECOMES MAG 3, MAG 1 BECOMES MAG 2)

2.4 CONTINUE REPEATING 2.1 AND 2.2 UNTIL MAG 1 AGAIN APPEARS ON TOP

The sequence should be r1, r2, r3, r4, r1

The second time MAG 1 appears on top, repeat 2.1 with the file name being MMMDDr1b

2.5 TOP VIEW OF THE VARIOUS ROTATION ATTITUDES (# INDICATES AXIS OF NEXT ROTATION)

```
    R1              R2              R3              R4
-----------     -----------     -----------     -----------

     2               1               4               3
     #                               #
     1               2               3               4
                   #                               #
 4       3       3       4       2       1       1       2

    R1B
-----------

     2

     1

 4       3
```

2.6 MAKE NOTE OF THE LEVEL BUBBLES

After completing the entire rotation process, examine the two level bubbles and make a WRITTEN NOTE of where they are. However, DO NOT ATTEMPT TO ADJUST THEM BACK TO LEVEL unless part of the bubble is going beyond the outer of the double lines.

If part of a bubble has gone beyond the outer of the double lines then make a written note of where both bubbles are and then adjust BOTH BUBBLES back to exact center between the lines

2.7 PUT THE DATA ON DISK AND SEND BACK TO DENVER

Include the rotation data along with the normal data sent back to Denver as described under normal procedure

3.0 MORRIS RESTART PROCEDURE

VERSION 1.0, 20JUN94

THE MORRIS RESTART PROCEDURE IS TO BE FOLLOWED ANY TIME THE 12/24-V POWER HAS BEEN LOST, THE POWER SWITCH HAS BEEN TURNED OFF, OR THE RED/YEL/BRN CABLE HAS BEEN DISCONNECTED

3.1 RE-ESTABLISH THE POWER THROUGH THE RED/YEL/BRN CABLE

Plug-in the RED/YEL/BRN cable
Connect the 12/24-V cables to the 12/24-V batteries
Turn-on the main power switch
Now you should hear the fans INSIDE Morris. The outside fans may or may not start

3.2 REMOVE THE LID FROM MORRIS

Unlatch the eight pull-down hasps that hold on the lid
Carefully and slowly lift the lid up until it has cleared all the surrounding equipment and wires and the upper seal has sufficiently separated from the lower seal
Set the lid in a location where the seal cannot be damaged and it is protected from wind-borne materials blowing onto the seal or into the lid
Be sure that the inside of Morris is also protected from foreign materials

3.3 CHECK FOR OBVIOUS PROBLEMS INSIDE MORRIS

Push the power connector and RS232 connector into the palm top computer to be sure they are making contact
WARNING: DO NOT REMOVE THE POWER CONNECTOR FROM THE PALM TOP COMPUTER WHEN POWER IS ON BECAUSE THE OUTER RING WILL SHORT CIRCUIT TO THE HOLE PLATE
Push the other end of the RS232 cable into the output connector on the internal utility strip
Visually inspect the cables for any obvious problems like missing insulation, short circuiting, etc
If necessary, reroute cables to avoid the fans and seals
Be sure the inside fans are running
Inspect the inside utility panel checking that the two toggle switches are in the R position and the red light is on
Be sure the palm top computer is sitting properly on its four corner blocks and the air holes underneath are clear
Check that nothing is blocking the air-holes on the upper hole plate

3.4 WAKE-UP THE PALM TOP COMPUTER

Open the lid of the palm top computer to reveal the key board and screen
If the screen is blank, push the ON button in the upper right
If the screen says so, push any key to get the file list
If a program is still running, push CNTRL-C and wait for it to stop with an error message. Then hit any key to get the file list
If the program does not stop, pull the RS232 cable out of the palm top computer. Replace when the program has stopped. Then hit any key to get the file list
Now you should have a list of programs on the screen with one of them highlighted in reverse video

3.5 RUN THE INITIALIZER, MELDIAG

Move the highlighted band using the up or down arrow keys to the program named MELDIAG
Hit return and wait for the MELDIAG screen to come up. The outside fans should start if they were not already running
Hit the space bar, type in 50 (50 percent duty cycle) and hit return, then type h (stands for heat) and hit return
Observe the temperatures which are updating:
- The Inside TE face TEMP should be increasing
- The Outside TE face TEMP should be decreasing slowly
- The internal TEMP will probably be railed at some weird TEMP like 33.01
- The external TEMP should be the outside air TEMP. Be sure it is functioning by putting your finger on the outside thermistor at the end of the black wire underneath the white styrofoam sun-guard on the outside of Morris. It should begin to increase immediately after placing your finger on it. It should decrease again after removing your finger.

Hit the space bar, type in 19 (19 percent duty cycle) and hit return, then type h (stands for heat) and hit return
The outside fans should stop
Again observe the temperatures:
- The Inside TE face TEMP should be increasing slowly or possibly stagnating
- The Outside TE face TEMP should be holding constant or changing very slowly

Now hit ESC. The MELDIAG screen should disappear and/or the message to hit any key may come up. After hitting any key, the list of programs will be displayed.

3.6 RUN THE TEMPERATURE HOLDING PROGRAM, TEDCNT8

WARNING: NEVER ATTEMPT A RUN OF THIS PROGRAM WITHOUT HAVING FIRST RUN MELDIAG AS DESCRIBED ABOVE.

Using the up or down arrows, scroll to the bottom of the list where you should find TEDCNT8 and hit return

After a short pause, the outside fans should turn on and the screen should have a new line of numbers dumped out every 2 seconds

The columns in the line of numbers are:
duty cycle, internal TEMP, inside TE, Outside TE, external TEMP. TEMPs are in Hundredths of degrees C.

The duty cycle should be 255
The internal TEMP should be railed near 3001
The inside TE should be increasing rapidly
The outside TE should be decreasing
The external TEMP should be the same as the outside air

3.7 CLOSE UP MORRIS

Close the lid of the palm top computer
Put the Morris lid back on:
LOOK INSIDE THE LID and find the single wide notch in the insulation. This notch goes on the fan side.
DO NOT PUT THE MORRIS LID ON BACKWARDS
Hook the eight hasps and turn them all down tight

3.8 OBSERVE THE MORRIS TEMPERATURE

Turn on the electronic thermistor box
Observe the Morris temperature increasing at about 0.1°C every few seconds
It should reach or pass slightly beyond 35°C within about 15 minutes. Complete stabilization at 35±0.2°C may not occur for up to 2 hours.
When thoroughly bored with watching the Morris TEMP, turn off the electronic thermistor box and go home

4.0 NORMAL SYSTEM RESPONSES

VERSION 1.0, 22JUN94

This section is intended to describe how the TMGS (Tensor Magnetic Gradiometer System) responds under normal circumstances. Abnormal responses may signify a problem requiring remedial action. Some remedies and tests are given here. HOWEVER, IF YOU OBSERVE AN ABNORMAL SYSTEM RESPONSE for which a solution has not already been provided, please make observations about the problem and CONTACT ONE OF THE FOLLOWING IN DENVER, CO:

Rob Bracken, (303) 236-1207, -1204, -1212, -1200
0900 to 1700 MDT
Email rbracken@musette.cr.usgs.gov

Tom Grover, (303) 236-1217, -1333
0630 to 1430 MDT

4.1 POWER CONSUMPTION

The TMGS has three basic circuits: 1) the 12/24-V Main Digital System (MDS) requiring two 12-V batteries in series, 2) the 12-V thermoelectric device (TED) circuit, and 3) the 12-V data acquisition system (DAS) computer power supply.

If the power consumption is noticeably above or below the constraints given below, there is something wrong. Please call Denver for further discussion.

4.1.1 THE MDS is connected to the aluminum power supply box via a harness of three cables marked GND, 12, and 24. To obtain the proper power, GND must be hooked to the negative post and 12 must be hooked to the positive post of battery A. Then the positive post of battery A must be jumpered to the negative post of battery B. 24 is then hooked to the positive post of battery B.

The net current flow out of each of the two MDS batteries is about 0.7 A. This current is fairly constant under all circumstances. A 90-Ah battery will be fully discharged after about 5 days. However, the voltage of each battery should not be allowed to fall below about 11 V because the minimum input voltage to the MDS voltage regulator is unknown.

Once the MDS has been started, the power from the 12/24-V batteries cannot be broken without requiring a complete restart (see Morris restart).

4.1.2 THE TED CIRCUIT is connected to the aluminum power supply box via a harness of two cables. One of the cables has red tape indicating that it should be hooked to the positive battery post of battery C. Of course, the other cable goes to the negative battery post.

The current flow out of the TED battery varies depending on the temperature felt by Morris. The current can range from 0 A to about 10 A. If the surface temperature of Morris varies within the range 17°C to 30°C, then the average current draw will probably be about 1 A. A 90-Ah battery would then be fully discharged after about 3 1/2 days.

The TED battery may be disconnected for short time periods (less than 2 minutes) without severely effecting the Morris temperature.

4.1.3 THE DAS COMPUTER POWER is connected to the computer power supply via a dual clip cable and a cigarette lighter adapter. WARNING: THE ADAPTER IS A POTENTIAL WEAK POINT IN THE CIRCUIT; IT SHOULD BE CHECKED PERIODICALLY. The positive cable is marked with red tape and should be connected to the positive post of battery D.

The current flow out of the DAS computer battery is about 0.9 A after the screen and disk drive have automatically shut down. A 90-Ah battery would be fully discharged after about 4 days.

If the DAS computer battery is momentarily disconnected, an internal computer battery is automatically switched in allowing the computer to continue running during short power interruptions. The internal battery is also switched in if the DAS computer battery voltage drops below a certain threshold. WARNING: THE INTERNAL COMPUTER BATTERY IS ONLY RECHARGED WHEN THE COMPUTER POWER SWITCH IS TURNED OFF (charging takes about 3 A). Unless a charging opportunity is provided, the internal battery will eventually become depleted at which time the computer operation will stop when the DAS computer battery is disconnected.

4.2 DAS COMPUTER READOUT

The DAS computer readout can be used diagnostically by running KMGS9 with a 1-second sample interval (and a junk file name). In this mode, the values returned by the magnetometers and their thermistors are sampled and updated on the screen every second. The display has two basic sections: raw data values and MAG values. Additionally, diagnostics may be made by examining data using KDISP6. Operation of this program is summarized above (see normal procedure section 1.5)

If any problem with a MAG or thermistor is uncovered, it is most likely located in a cable, connector, or dirt and corrosion in a connector. If checking these does not reveal the problem, then call Denver for help.

4.2.1 DIAGNOSTICS FROM THE RAW DATA SECTION are most easily done by performing the DISCONNECT/RECONNECT test. If a magnetometer or thermistor circuit is not functioning, chances are that its value will be railed at some idle value. This condition can be checked by disconnecting the MAG cable or thermistor cable where it comes into Morris. If a problem exists, one or more of the displayed values associated with the disconnected cable will not change. Conversely, if all the circuits are working, when the cable is disconnected, all values associated with that cable will begin changing toward their idle values.

Sometimes, the bin values of one of the MAGs will stick a while after a cable is disconnected. Eventually, however, they will go toward a large number like 165 or 252. The idle TEMP of the thermistor circuits is, unfortunately, about 25°C. Consequently, if the thermistor TEMP is near

25°C, it becomes difficult to discern whether or not it is working. If this occurs, the best check is to compare the thermistor data from a long time period (> 12 hours) using KDISP6.

If a bad circuit is discovered using the disconnect test, the problem is most likely located in the cable, connector, or dirt and corrosion in a connector. If checking these does not reveal a problem, then call Denver for help.

4.2.2 DIAGNOSTICS FROM THE MAG VALUES SECTION include observations of the absolute values and variations in the data stream.

The total field values of all four MAGs should be within about ±1000 nT of each other as well as being in the ball park of expected total field MAG values.

The component values (x,y,z) of each MAG should be appropriate for its attitude. The top MAG (MAG 1 unless a different MAG has been rotated on top during a rotation calibration) should have x pointing magnetic north, y pointing east, and z pointing down (right hand orthogonal coordinate system). Roughly, x will be +28000, y near 0, and z about +15000. The other MAGs are in other attitudes. Examination of their attitudes should give you a rough idea of whether or not their component values are correct. The geometry of the tetrahedron dictates that the y components of MAGs 1 and 2 should be close to zero and MAGs 3 and 4 should have y components similar in magnitude but opposite in sign

Most short term (sample to sample) variations in the data stream are caused by system noise. These variations are usually less than 0.2 nT. If any component consistently shows larger variations (and a magnetic storm is not in progress), then there is an electrical problem with that axis. A call to Denver should be made.

4.2.3 DIAGNOSTICS FROM COLLECTED DATA should be performed as part of the normal procedure (see normal procedure section 1.5). Using program KDISP6, examine each axis of each MAG and the four-thermistors' data. Indications of problems include: horizontal lines, step functions, white noise larger than 0.5 nT, or other conspicuous variations.

An occasional step function of either 327 nT or 500 nT IS NOT A PROBLEM. These are the normal binning function of the magnetometer. Because of the limited dynamic range of KDISP6, a binning related step will probably cause the entire profile to appear as a horizontal line.

Comparison of axes is useful. Larger magnetic variations will often show up on different axes with differing amplitudes but similar wavelengths. Observing these is sometimes useful in confirming that a particular noise is in fact geomagnetic in origin.

Variations on the y axes of MAG 1 and MAG 2 should be almost exact mirror images of one another. So also should be the variations on the y axes of MAG 3 and MAG 4.

The four thermistor values should all vary similarly. If one of them is doing something significantly different than the rest, there is something wrong.

4.3 MORRIS TEMPERATURE

The Morris TEMP is the TEMP at a specific location inside the grey electronics housing box named Morris. It is measured by an independent battery operated calibrated thermistor. The readout of the thermistor is housed in the small aluminum box with the switch and readout on the front. The Morris temperature must be maintained at 35°C during data acquisition periods.

4.3.1 THE TYPICAL MORRIS TEMPERATURE RANGE when at equilibrium, is from 34.8°C to 35.2°C according to the electronic thermistor box. Occasionally, it may drop to 34.7°C or rise to 35.3°C during transition periods where a tarp has just been removed or if a sharp TEMP change has occurred outside. ANY VARIATION BEYOND THIS RANGE SIGNIFIES A PROBLEM WHICH MUST BE SOLVED.

If variations are occurring outside this range, data can still be taken while the problem is being solved. However, the time period of and the characteristics of the variations must be noted and made to accompany the data.

4.3.2 THE EXPECTED MORRIS TEMP CHARACTERISTICS DURING A RESTART are as follows: Assuming the Morris TEMP is below 35°C at the time of restart, the initial characteristic will be a quickly increasing TEMP of 0.1°C every several seconds. It will usually cross 35°C in about 15 minutes. At this time, the temperature holding portion of the program kicks in. Usually that is followed by a slow decrease in TEMP bottoming out 30 minutes later at 33.5°C or higher. Then there will be a slow increase in TEMP stabilizing between 34.8°C and 35.2°C. This final phase may take as long as 2 hours but, under some circumstances, the entire process may complete within half an hour. If after 2 hours it has not yet stabilized, there is something wrong.

4.3.3 FIXING MORRIS TEMPERATURE ABERRATIONS is more of an art than a science. However, there are a few tests that can be performed to reveal what is wrong. Execute the procedure described in the following paragraphs. If there is still no improvement, call Denver and supply as many written observations as possible for telephone diagnosis.

4.3.3.0 THIS PROCEDURE ASSUMES that you have returned to Morris after a period of data acquisition and discovered the TEMP to be outside the acceptable range; OR that you have attempted the Morris restart once and allotted enough time to confirm that the temperature is not following the pattern given in 4.3.2 (Morris restart characteristics).

4.3.3.1 CHECK THE RELIABILITY OF THE ELECTRONIC THERMISTOR BOX. First flip its power switch off and on again. Then place the box on top of Morris and move your hands well away from it. Read the temperature several seconds later. If no improvement, check the electronic thermistor box cable for damage. Also, unplug and re-plug its connectors. If still no improvement, check the battery voltage in the electronic thermistor box by measuring between the extra wire coming out of the back and the metal box surface. If the voltage is below 7.0 V while the box is turned on, replace the 9-V battery inside.

4.3.3.2 CHECK THE POWER TO THE MDS (12/24-V) SYSTEM. Be sure the voltage on the 12/24-V batteries is above 11 V each and that the main power switch is turned on. Also, check that the YEL/RED/BRN cable is connected to Morris on the MAG cable side.

4.3.3.3 CHECK THE POWER TO THE TED SYSTEM. Measure the voltage at the deep cycle battery input to the TED system. If this battery is below 11 V, that may be the problem. Check to be sure the BLU/GRN/BLK cable is connected to Morris on the fan cable side.

4.3.3.4 CHECK THE TED DRIVING VOLTAGES. Put a voltmeter across the two lugs located at the bottom of the terminal strip on the fan side of Morris. Observe the voltage. Then disconnect the BLU/GRN/BLK cable plug and immediately observe the voltage again. Plug the cable back in after noting the unplugged voltage. If the difference between the two voltages is greater than about 0.3 V, the TED drive is probably okay. If it is less than 0.3 V, continue observing the voltage with cable plugged back in. If the TED drive is okay, you will eventually see a quantized step change in the voltage of at least a quarter of a volt. If the TED drive is NOT okay, then the system must be re-started (see 3.0, Morris restart). If the TED drive IS okay, then observe the Morris TEMP for a while longer; it should stabilize.

4.3.3.5 IF NO OBVIOUS PROBLEMS CAN BE TURNED UP, carefully repeat the Morris restart procedure from beginning to end and take careful notes about how each system component is responding. Note how the Morris TEMP is behaving. And note weather conditions including rain, sun, variable clouds, wind gusts, and outside air TEMP. Then if it still does not stabilize, call Denver with the notes.

APPENDIX B. FIELD NOTES

The following notes were collected by Gary Puniwai (of the HVO staff) during the tenure of the TMGS in Hawaii. The monitoring period began on June 13, 1994; comprehensive notes began being taken on June 27.

In the left margin, dates and times have been translated into decimal day of the year 1994 as defined in Appendix F. The part of the decimal day left of the decimal point (e.g. 178) is adjacent to the date (e.g. Jun 27, 1994); the decimal fraction of the day (e.g. .546) is adjacent to the time (e.g. 1306). This translation has been added to facilitate comparisons between these notes and other aspects of the project, which may use decimal day of the year 1994 (e.g. base 10 time lines).

FIELD NOTES - by Gary Puniwai

178	Jun 27, 1994	
.546	1306	BATTs: 16.24, 16.20, 16.15, 16.14 V
		Weather: light drizzle, weak sun
		TEMP: 41.7°C, BATT: 9.3 V
		MAG 1 Y field @ -732.00 nT
		MAGs X+Y+Z BIN values 0, DEVIATIONS -6.5 V, TEMP -65.54°C
		Date on computer screen 6-25-94, 08:57
		no response on computer keyboard, rebooted computer
		screen on HP100 said link lost
		ran MELDIAG, testing T.E.: okay
		ran TEDCNT8, screen display looks okay
		ran KMGS9, computer hangs up, must reboot
		computer time 01:29:05p, real time 13:29:20
		reset computer time
		TEMP: 37.8°C
		disconnected AST computer

179 Jun 28, 1994
.415 0957 TEMP: 32.8°C
Voltages on BATTs: 16.07 V on panel: 16.22 V
16.17 16.50
13.47 13.59
13.24 13.31
can hear internal Morris fans
installed AST, reset computer time
run KMGS9, no keyboard response to U, reboot
HP100: display says control link lost, TED terminated
turned main power switch off
.426 1013 turned main power switch on
run MELDIAG, seems okay
run TEDCNT8, screen: 255 -1 3001 2887 2800 3770
255 -1 3001 2843 2756 3790
TEMP: 31.3°C, then 31.5°C
checked cables, all in proper location
.430 1019 run KMGS9, looks operational; TEMP 31.7°C

	X field	Y field	Z field	tot
MAG 1	57940	78989	-112674	149304 nT

TEMP: 31.8°C
2 data samples taken
TEMP: 32.1°C
covered system
.432 1022 outside TED fans came on
computer-left led light not blinking
left site

.626 1501 TEMP: 42.1°C
KMGS9 working okay
MAG values on #1 look high
BATTs: 16.09, 16.16, 16.08, 15.96 V
can hear TE fans inside, outside fans not on
X,Y,Z, BIN, DEVIATIONS, TEMP look okay

MAG	X field	Y field	Z field	Tot field
1	82969	75927	1534.1.6	113506.0 nT
2	-5873	-14.4	-7654.5	9648
4	-11341.2	218891.6	8503.6	32181.7

HP100 screen display
237 3997 3893 3281 3985 11800 6871
20 1 3397 3893 3281 3985 12
WARNING: CONTROL LINK LOST
TED CNTRL TERMINATED
run MELDIAG, okay
run TEDCNT7,screen: 255 1 3314 3725 3062 2852
turned off main power switch, checked Morris fuse-okay
.635 1515 turned power on; run MELDIAG and TEDCNT7
TEMP: 34.1°C, 34.4°C
TEMP: 34.7°C, outside TE fans shut off
.639 1520 run KMGS9, values look okay on MAG 1
TEMP: 34.9°C
.642 1524 TEMP: 35.1
.643 1526 TEMP: 35.2
.644 1528 TEMP: 35.3

```
 179   Jun 28, 1994 (continued)
.646  1530 TEMP: 35.4°C
.648  1533 TEMP: 35.5
.650  1536 TEMP: 35.6
           opened Morris
           TEMP: 31.1
           HP100: -14  3349  3281  2756  2715  -174  660
.652  1539 outside TE fans came on
           TEMP: 29.7°C
           closed Morris
           TEMP: 33.0°C
           KMGS9 data looks okay
.653  1541 TEMP: 33.3°C, 33.4°C
.655  1543 covered station, left site

 180   Jun 29, 1994
.483  1136 TEMP: 40.9°C, outside fans on
           data values look good, hit END
           Morris outside of box warm to touch
           BATTs: 15.66, 16.22, 16.00, 15.35 V
           copied data to floppy
           used KDISP6, MAG data looks okay except for last hour?
             TEMP data looks okay
           TEMP: 41.2°C, BATT: 9.1 V
           started KMGS9, Jun29m8m
           TED test term: -0.241 V, outside fans running
             disconnected cable, -0.270 V (fans off)
             reconnected cable, -0.244 V, fans on
           TEMP: 41.3°C
           number of data samples @ 5, looks okay
           raised green tarp to act as shade for blue tarp
.509  1213 TEMP: 41.4°C
           outside TE fans has been running all this time
           left site
```

181	Jun	30, 1994
.399	0935	TEMP: 33.0°C, only internal fans on
		BATTs: 13.40, 16.47, 13.65, 13.20 V (PC/TED/DAS/DAS)
		(BATT for TE high because no pwr used thru night?)
		TE: -0.05 V
		data looks good, samples @ 658
		improved tarp system
.415	0958	HP100: control link lost, TED control terminated
		screen: 237 3997 3850 2975 3965 11209 6208
		turned main pwr switch off, disconn then reconn BATT
		turned main power on
		disconnected solar panels except for computer
		BATTs: 13.51, 13.80, 13.33, 13.15 V
		run MELDIAG and TEDCNT8
.427	1015	TEMP: 30.2°C, TE: -0.06 V
		computer time 10:16:07, real time 10:15:45
		reset computer time
		run KMGS9 with 2-second interval
		TEMP: 30.6°C, TE: -0.12 V
.433	1023	TEMP: 31.0°C, TE: -0.14 V
		computer BATT with panel: 13.58 V
		data looks good
		run KMGS9, 120 second interval
.438	1031	TEMP: 31.3°C, TE: -0.162 V
		TED BATT: 12.76 V
		outside fans have been on since power up
.442	1037	TEMP: 31.6°C, TE: -0.163 V
		disconnected TE connector, no change in voltage
.446	1042	TEMP: 31.8°C, TE: -0.172 V
.450	1048	TEMP: 31.9°C, TE: -0.186 V
.453	1052	TEMP: 32.1°C, TE: -0.186 V
		opened up TED power box
		Magic Module: input 25.63 V, output 12.14 V-okay
		fuse looks okay
		visual inspection: no obvious bad components
		closed power box
.458	1100	TEMP: 32.3°C, TE: -0.168 V
.463	1106	TEMP: 32.5°C, TE: -0.180 V
		left site

181 Jun 30, 1994 (continued)
arrive again
.586 1404 TEMP: 37.5°C, TE: -2.33 V
HP100 screen: 209 3661 3500 2887 3145 8761 6900
run MELDIAG with 9 and 25% duty cycle, test okay
TEMP: 30.0°C, TE: -0.09 V
disconnect power to TE, no change in voltage
MELDIAG test

Duty Cycle	H/C	TEMP	TE conn.	TE discon.	outside fans
3	H	30.1°C	-0.086 V	-0.084 V	off
3	C	30.0	-0.077	-0.076	off
19	H	29.8	-0.073	-0.072	off
19	C	29.8	-0.070	-0.070	off
20	H	29.6	-0.067	-0.066	on
20	C	29.5	-0.066	-0.066	on
40	H	29.4	-0.063	-0.063	on
40	C	29.2	-0.063	-0.063	on
99	H	29.8	-0.062	-0.061	on

60 H and 60 C no change in TE TEMP
external amb sensor: 29.10°C, touched w/ finger-TEMP rose to 30.10°C
moved HP100 outside of Morris
.615 1446 run TEDCNT8
HP100 screen: 255 -1 3052 2843 2668 2930
255 -1 3056 2843 2668 2930
255 -1 3064 2843 2668 2872
255 -1 3075 2887 2625 2833
TEMP: 30.3°C
.620 1453 started KMGS9
HP100 screen: 255 -1 3118 2931 2668 2930
TEMP: 30.7°C., TE: -0.11 V
.626 1501 BATTs: 12.70, 12.70, 12.69, 12.54 V
outside fans still on
TEMP: 30.9°C
HP100 screen: 255 -1 3161 2931 2625 2793
Temperatures: rising stable rising rising
at terminal strip outside Morris:

	wire color	VOM reading
highest cable	bare	common
	Black	0.064 V
	Red	0.469
middle cable	bare	common
	Black	0.185 V
	Red	0.578
lowest cable, goes to TE conn.	bare	common
	Black	4.96 V
	Red	4.66

.631 1508 TEMP: 31.4°C, TE: -0.151 V
HP100 screen: 255 -1 3197 2975 2625 2754
Temperatures: rising stable stable rising
left site

182 Jul 1, 1994

.389 0920 TEMP: 31.7°C, TE: -0.083 V, outside fans on
BATTs: 12.43, 12.55, 12.44, 12.36 V
Data looks okay, samples @ 273
Computer is hung up, screen date 06-30, 23:59:41
  reboot computer
HP100 screen: 255 -1 3240 3062 2800 3340
turned off main power switch
opened power box
  test TE power cable, all continuities okay
  removed fuse, tested okay
  closer inspection of 2 transistors with heat sink on
    perf board shows slight bubble-probably bad (these
    are the same parts I mentioned a few days earlier)
    inscriptions on parts: IIVN __OOM C9052 | IIVP __OOM C9052
closed power box
run MELDIAG

duty cycle		Red lead	Black lead
9	H	0.401 V	4.91 V
9	C	0.401	0.00
30	H	1.34	4.91
30	C	1.34	0.00
50	H	2.28	4.91
50	C	2.28	0.00
99	H	4.63	4.90
99	C	4.63	0.00

turned off HP100, disconnected TE power cable
computer time 10:01:03, real time 10:01:00
reset computer time

.420 1005 run KMGS9

.421 1006 hooked up solar panels to computer and DAS BATTs
BATTs: 12.69, 12.64, 12.90, 12.63 V
TEMP: 32.0°C
Morris feels comfortable to touch, not warm
weather sunny, wind 25+ mph
tied tarps down better

.433 1023 opened Morris, put HP100 inside, closed Morris
TEMP: 32.3°C
BATTs: 13.14, 12.65, 13.18, 13.03 V
data samples @ 11
left site

```
 186   Jul  5, 1994
.424  1011 Computer screen looks okay, correct date and time,
             samples @ 2885
           TEMP: 32.7°C
           BATTs: 13.25, 12.59, 13.45, 13.35 V
             checked water levels, put some water in PC BATT
           left computer led blinking as usual
           can hear internal fans on
           used KDISP6, data looks okay
           computer time 10:24:10, should be 10:23:15
           reset computer time
           insufficient floppy disk space, cannot dump data
           started KMGS9
.435  1026 TEMP: 32.9°C
           Weather: overcast, drizzling, wind 10-20 mph
           left site

.547  1307 arrived at site
           TEMP: 36.3°C
           data on MAGs 1 & 2, Y BIN = 0
           data samples @ 81
           copied data to floppy
.550  1312 started KMGS9
           TEMP: 36.4°C
           Weather: partly cloudy, some drizzle, wind 10-20 mph
           data on MAGs 1 & 2, Y BIN =0, MAGs 3 & 4,
             Y BIN = -88 and 88

 189   Jul  8, 1994
.538  1255 TEMP: 41.8°C
           BATTs: 16.33, 12.57, 16.30, 16.20 V
           Dumped data to floppy
           Turned power supply off, turned computer off
           Disconnected power supply from barrier board
           Disconnected solar panels from barrier board
.547  1307 Removed computer and power supply
```

201	Jul	20, 1994
.455	1055	BATTs: 11.91, 12.53, 12.85, 12.73 V
		hooked up solar panels and power supply
		BATTs: 12.63, 13.40, 14.56, 15.07 V
.459	1101	Turned power supply on
.463	1106	Run MELDIAG
		with 19 and 25 duty cycle, fans respond correctly
		Run TEDCNT8
		screen: 255 -1 3001 3543 2362 2774
		stable rising dropping dropping
.466	1111	TEMP: 27.3°C
.467	1113	Started KMGS9
		TEMP: 31.0°C
.470	1117	started to fill ram
		TEMP: 31.9°C
.472	1120	stopped KMGS9, reset computer time
.474	1122	started KMGS9, file Jul20m8a
		TEMP: 33.7°C, outside fans shut off
		all MAG DEVIATIONS @ -3.26 V, all BIN @ 64,
		all TEMPs @ -32.64°C
.476	1125	Weather: sunny, wind +20mph

```
 202   Jul 21, 1994
.376  0902 TEMP: 34.7°C, outside fans off
           Data samples @ 650
           All BIN vals @64, all DEVIATIONS @-3.264 V,
              all TEMP @-32.64°C
           Total fields @ 54771, 54792, 35607, 35800
           BATTs: 12.34, 14.44, 13.21, 13.02 V
           Opened power supply
             Magic module: in 26.2 V, out 12.4 V
             fuse looks okay
             visual inspection-looks okay
           closed power supply
.385  0915 used KDISP6, all data flat lines
           TEMP: 34.7°C
           Turned power supply off
           Switched computer and TED BATTs
           filled water in all BATTs
.390  0921 Turned power supply on
           run KMGS9, all values look okay
           TEMP: 33.6°C, BATT: 9.17 V
           BATTs: 13.62, 12.22, 13.29, 13.13 V
           Opened Morris
             run MELDIAG, tested w/19 and 25% duty cycle, fans ok
             run TEDCNT8
               screen: 255 -1   3001   3981   2275    2208
                                stable rising dropping rising
           closed Morris
           TEMP: 31.1°C and rising, outside fans on
.399  0934 data looks okay, stopped KMGS9
           reset computer time
.401  0937 run KMGS9, file jul21m8m.dat, all vals look reasonable
           TEMP: 34.2°C, outside fans shut off, TED BATT: 12.17 V
           Weather: heavy overcast, drizzle
           left site

           arrive site
.551  1314 TEMP: 34.7°C, outside fans off
           Data values look okay, samples @ 109
.557  1322 Replaced TED BATT
           BATTs: 15.80, 14.50, 13.73, 13.54 V
             old TED BATT: 12.53 V - no load
.559  1325 Data samples @ 114
           TEMP: 34.8°C
           Weather: overcast, ground dry, possibility of sun,
             winds +15mph
```

206	Jul	25, 1994
.558	1323	TEMP: 34.9°C
		Outside fans cycling on and off
		BATT: 16.10, 15.80, 16.22, 16.19 V
		Data values all look reasonable
		Time 13:29:26, real time 13:29:30
		reset computer time
		Used KDISP6, data looks okay
.563	1331	Started KMGS9, stopped program
		Dumped data to floppy
.567	1336	Started KMGS9, data looks reasonable
		TEMP: 34.9°C
		Weather: sunny, windy
		left site
210	Jul	29, 1994
.675	1612	TEMP: 34.9°C
		Date & data look okay, samples @ 2959
		BATT: 16.09, 15.74, 16.19, 15.36 V
		Outside fans are off
		Stopped program
		Computer time 4:18:35p, real time 16:18:40
		reset computer clock
		Used KDISP6, data looks reasonable
		Dumped data to floppy
.681	1620	Started KMGS9, file Jul29m8m
		TEMP: 34.9°C
		Topped off BATT water
.684	1625	Samples @ 2, data looks okay
		TEMP: 34.8°C
		Weather: sunny, winds 10-15mph
		left site
220	Aug	8, 1994
.443	1038	TEMP: 34.8°C
		Outside fans off
		Computer date 7-31-94, time 23:58:20, samples @ 1669
		hit END- no response, computer is locked up
		BATT: 13.66, 16.24, 14.22, 13.97 V
		Reboot computer
		computer time: 10:41:32?, actually 10:42:10
		computer time: 10:41:38?, actually 10:42:10
		reset computer time
		Run KMGS9 with 2-second sampling, data looks okay
.448	1045	Run KMGS9 with 120-second sampling
		TEMP: 34.8°C
.454	1054	Filled water in BATTs
		TEMP: 34.7°C
		Data samples @ 4
		Weather clear & sunny
		left site

221	Aug	9, 1994
.385	0914	TEMP: 34.6°C, outside fans off
		Computer date & time okay, samples @ 675
		hit END
		BATT: 13.26, 15.50, 13.48, 13.31 V
.387	0917	TEMP: 34.6°C
		Copied data to floppy
.389	0920	TEMP: 34.5°C
		Used KDISP6, data looks reasonable
		Opened Morris
		HP display: 5 3353 3193 3543 3243 -524 -191
		turned power supply off
.392	0924	turned power supply on
		Run MELDIAG, outside fans respond correctly
.393	0926	Run TEDCNT8
		HP display: 255 -1 3204 4593 2931 3321
		Closed Morris
.394	0927	TEMP: 34.2°C
		Computer time 09:28:12, real time 09:28:00
		reset computer time
		Outside fans shut off
		TEMP: 35.2°C
.395	0929	Started KMGS9
		TEMP: 35.1°C
		MAG 1 Y field @ 128078
		MAG 1 total field 181346
		MAG 2 total field 10456
.402	0939	Left money, keys, and glasses outside of lava tube
		Inspect TESSA, level bubbles ok, everything looks ok
.403	0940	TEMP: 34.5°C, outside fans off
		BLU/GRN wire at bottom of terminal strip 1.629 V
.409	0949	TEMP: 34.4°C
		left site

222	Aug	10, 1994
.474	1122	TEMP: 34.9°C
		Computer date & time okay, samples @ 776
		MAG 1 total field 181346 nT
		MAG 2 total field 10467
		Stopped KMGS9, copied data to floppy
		Computer time 11:27:14, real time 11:27:00
		reset computer time
.478	1128	TEMP: 35.0°C
		Disconnected cable from MAG 1, no change in values
		Disconnected cable from MAG 2, slight drop in values
		Disconnected cable from MAG 4, large change in values
		Opened Morris
		turned power off, then on
		run MELDIAG then TEDCNT8
		run KMGS9, no data, computer locked up
		cycled power three times before KMGS9 worked
		(displayed data)
.489	1144	Data on KMGS9, 2-second sampling, values look okay
		TEMP: 35.5°C
.490	1146	Started KMGS9 with 120-second sampling
		TEMP: 35.4°C
.492	1149	TEMP: 35.2°C, BATT: 8.69 V
		samples @ 1, all values look okay
		Weather sunny
		left site
227	Aug	15, 1994
.503	1205	Computer date and time okay, samples @ 3610
		TEMP: 35.0°C
		Outside fans cycled on and off
		BATT: 15.73, 16.01, 16.11, 16.13 V
		Tried 3 times to access A: drive,
		error: not ready reading drive
		finally accessed A:drive, dumped data to A: drive
		Computer time 12:13:46, actually 12:12:40
		reset computer time
		Used KDISP6, data looks okay
.511	1216	Started KMGS9, file Aug15m8m
		TEMP: 34.9°C
		Weather: clear & sunny, winds 10-15mph
		Program running okay, samples @ 2, values look okay
		left site

234	Aug	22, 1994
.576	1350	Filled water in BATTs
		Computer & data okay, stopped program
		dumped data to floppy
		TEMP: 35.4°C
		Used KDISP6
		MAG 2, X-axis looks flat, could be scaling
		Computer time 14:10:23, actually 14:09:00
		reset time
.592	1413	BATTs: 16.17, 15.87, 16.31, 16.29 V
		Started KMGS9
		data values look okay
		TEMP: 35.2°C, BATT: 8.67 V
		Data samples @ 2
		Weather clear & sunny, wind +25 mph
241	Aug	29, 1994
.590	1410	TEMP: 34.9°C
		Computer date & time okay, samples @ 5041
		All data values look okay
		BATTs: 16.15, 15.66, 16.19, 16.18 V
		water levels okay
		Outside fans cycling on and off
.596	1418	Dumped data to floppy
		Computer time 14:21:22, actually 14:20:00
		reset time
		Used KDISP6, data looks okay
.599	1422	Started KMGS9
		TEMP: 34.9°C
		Samples @ 3, data looks reasonable
		Weather clear & sunny, wind +10mph
249	Sep	6, 1994
.442	1037	Computer date & time: 08-31-94, 23:58:00
		No response from keyboard, reboot computer
		TEMP: 34.7°C
		BATT: 13.51, 16.05, 13.73, 13.63 V
		filled water into BATTs
		Can hear internal fans running
		Computer time 10:39:29, actually 10:40:10
		reset computer time
		Run KMGS9 with 2-second timing, values look okay
.447	1043	Run KMGS9 with 120-second sampling
.451	1049	TEMP: 34.7°C
		Data samples @ 3, values look okay
		Weather overcast & drizzling, light wind

255 Sep 12, 1994
.483 1136 TEMP: 35.0°C, BATT: 8.72 V
Computer date & time okay, samples @ 4348
Outside fans cycling
BATT: 14.02, 15.97, 13.92, 15.27 V
Saved data, copied to floppy
Computer time 11:44:05, actually 11:42:00
Reset computer time
Used KDISP6, data looks okay
.490 1145 Started KMGS9
TEMP: 35.0°C
Weather partly cloudy, light winds
.491 1147 Samples @ 1, data looks okay
left site

263 Sep 20, 1994
.453 1052 Computer date & time correct
TEMP: 34.7°C, BATT: 8.71 V
Saved data, samples @ 5735, copied data to floppy
Used KDISP6, MAG 1-2-3-4 X & Y axis look okay
Computer time 11:01:53, actually 11:00:15
Reset computer time
.460 1102 Started KMGS9
Filled water in BATTs
.463 1107 TEMP: 34.7°C
Samples @ 3, data values look okay
Weather overcast, ground is wet
(Raingauge 4 miles northeast of this site recorded 18+ inches for the past week)
left site

269 Sep 26, 1994
.491 1147 TEMP: 35.0°C
Computer date and time okay, samples @ 4344
BATT: 14.34, 15.57, 13.91, 15.80 V
Copied data to floppy
Problems copying data to floppy, worked after 3 tries
drive doesn't like floppy (could be dirty head)
Used KDSP6, MAG 1 & 2 X axis looks okay
Computer time 11:56:37, actually 11:55:00
reset computer time
.497 1156 Started KMGS9
Data values look okay
TEMP: 35.0°C
Weather clear & sunny

```
 276   Oct  3, 1994
.454   1054 Computer date & time 9-30-94, 23:58:00
              no response from keyboard, reboot computer
            TEMP: 35.0°C
            Computer time 10:55:34, actually 10:56:00
              reset computer time
.457   1058 Started KMGS9
            All data values look okay
            Weather overcast, light winds
            Samples @ 2, data looks okay

 284   Oct 11, 1994
.443   1038 TEMP: 34.8°C
            Computer date & time okay, samples @ 5752
            BATT: 13.54, 15.61, 13.43, 13.81 V
            Computer time 10:48:57, actually 10:47:00
              reset computer time
            Filled water in BATTs
            Used KDISP6
              MAG 1-2-3-4 X-axis looks okay
              TEMP 1-2-3-4 looks okay
.451   1049 Started KMGS9
            TEMP: 34.8°C
            Data samples @ 2, values look okay
            Can hear internal fans, outside fans haven't cycled
              today
            Weather clear and sunny, light winds
            Disconnected one solar panel from temperature supply
              BATT now 15.10 V

 290   Oct 17, 1994
.582   1358 Computer date and time okay, samples @ 4415
            TEMP: 34.9°C
            Weather: raining
            BATT: 12.66, 14.34, 12.78, 12.91 V
            Copied data to floppy
.585   1403 Started KMGS9
            Cannot check time since I didn't bring a digital watch
            Data values look okay
            Samples @ 1
            left site
```

294	Oct	21, 1994
.388	0919	TEMP: 34.6°C
		Computer date & time okay, samples @ 2740
		Tried dumping data to floppy, cannot
		Tried another floppy, okay
		Used KDISP6, data looks okay
.395	0929	Started OCT21R1 rotation
.405	0943	Started OCT21R2
		Found 0 bytes in file
.407	0946	Started OCT21R2B
		Found 0 bytes in file
		Found computer disk full
		Deleted June data
		Started Oct21r2d
		Cannot find file, deleted all oct21r files
.413	0955	Started Oct21r2, file size 31K
.420	1005	Started Oct21r1, file size 31k
.427	1015	Started Oct21r3, file size 31K
.433	1023	Started Oct21r4
.439	1032	Started Oct21r1b
		Computer time 10:36:02
		Reset time to 10:34:20
.441	1035	Started KMGS9
		Values look okay
297	Oct	24, 1994
.449	1046	Computer date & time okay, samples @ 2166
		TEMP: 35.2°C, BATT: 8.71 V
		BATT: 13.30, 14.38, 12.93, 13.55 V
		Copied data to floppy
		Used KDISP6, MAG 1 & 2 X-axis looks okay
		Computer time 10:54:30, actually 10:53:30
		Reset time
.455	1055	Started KMGS9
		Filled water in BATTs
		Weather: sunny, light winds
.456	1057	Samples @ 1
304	Oct	31, 1994
.593	1414	Computer date & time okay, samples @ 5141
		TEMP: 34.9°C
		Water in BATTs okay
		Tarp rope broke, fixed problem
		Saved data to floppy
		Computer time 14:20:37, actually 14:19:00
		Reset computer time
		Used KDISP6
		MAG 1 & 2, X axis looks okay
.598	1421	Started KMGS9
		Data values look okay
		TEMP: 35.0°C
.599	1423	Samples @ 1
		Weather: overcast, light wind, area is wet

312	Nov	8, 1994
.390	0921	Computer date: 10-31-94, time: 23:59:40
		Samples @ 289
		Hit many keys-no response except beeps
		Reboot computer
		Deleted July data, 1.2 Mb free
		Computer time 09:46:58, actually 09:47:20
		Reset time
		Ran KMGS9 with 1-second sampling
		Data values look okay
.410	0950	Ran KMGS9, 120 seconds/sample
		TEMP: 34.8°C
		Data values all look okay
		BATT: 12.58, 13.52, 12.35, 12.77 V
		Weather: some drizzle, overcast
.412	0953	Samples @ 2
		Data values look okay
318	Nov	14, 1994
.454	1054	Computer date & time okay, samples @ 4353
		TEMP: 28.2°C, bat: 8.72 V
		BATT: 12.60, 13.92, 11.95, 12.61 V
		Saved data, copied to floppy
		MAG 1 and 2, X axis and TEMP seem okay
		Fixed broken tarp tie down
		Probable bad BATT, didn't restart KMGS9
.555	1319	Replaced one BATT (12 out of 24 V system): 13.43 V
		Turned power supply off, turned system on
		Tested HP with MELDIAG, ran TEDCNT8 system checks out okay
		MAG 1 and 2 values seem wrong, totals 50000 & 10000
		Cycled system power
		Tested system with MELDIAG, ran TEDCNT8
		BATT: 12.96, 13.01, 13.94, 12.91 V
		Turned power supply off, disconnected/reconnected pwr connector
		Tested system with MELDIAG, ran TEDCNT8
		Started KMGS9 with 1-second sampling
		MAG 1 50000, MAG 2 10000
		switched MAG connectors around, problem in DAS
		Computer time 13:40:53, actually 13:41:10
		Reset time
.571	1342	Started KMGS9, 120 seconds/sample
		TEMP: 34.1°C
		MAG 1 and 2 total field values still look wrong
		Weather: sunny, windy
		Samples @ 1

319 Nov 15, 1994 - Nov 17, 1994
Rob Bracken worked on system

(RB NOTE: The independent temperature monitor which measures the Morris temperature referred to in the notes as "Display TEMP:" or simply "TEMP:" was taken back to Denver for repairs and modifications. It was sent back and reinstalled on Dec 1, 1994.)

325 Nov 21, 1994
.583 1400 Hit <CNTRL> key, no response, screen stays dark
BATT: 12.50, 13.94, 12.43, 12.03 V
Turned computer off/on, doesn't start
Removed computer-brought to HVO
@HVO portable computer works ok, left on charge overnight

326 Nov 22, 1994
.403 0940 Changed computer 12 V BATT, installed computer
BATT: 13.40, 13.33, 12.13, 11.69 V
Replaced both DAS BATTs
BATT: 13.21, 13.27, 13.35, 13.09 V
.413 0954 Set computer time
Ran KMGR with 0.2-second sampling
All values seem reasonable
.414 0956 Ran KMGR, file Nov22m8m
Weather: overcast, drizzling
.417 1000 Samples @ 1, Total fields: 31436 to 32181 nT
TEMP: 20.08°C to 22.11°C
X BIN: +11 to 57
X DEVIATION: -2.8 to 0.6 V
Y BIN: -88 to 0
Y DEVIATION: 0.58 to 4.17 V
Z BIN: -63 to 26
Z DEVIATION: -0.35 to 2.25 V
left site

333 Nov 29, 1994
.463 1107 Computer reads: Date 11-22, time 09:56:19
Samples @ 5039, sub samples @209
.464 1108 Hit END, saved data
Copied data to floppy, 2 tries failed, 3rd try worked
Deleted September data
Used Kdisp6
MAG 1-4 X axis looks okay, MAG 1 & 4 TEMP okay
Computer time 10:02:16, actually 11:13:10
Reset time
.468 1114 Started KMGR
All values look okay
BATT: 12.65, 13.48, 12.71, 12.67 V
Weather: had weak sun earlier, now raining
Samples @ 1, everything looks okay

```
 335   Dec  1, 1994
.553  1316 Computer date 11-29, time 12:54, samples @ 1498
           Installed temperature display
           TEMP: 35.5°C
           MAG 4 TEMP: 23.73°C
           Multiplexer BATT: 12.72 V
           Installed multiplexer on TEMP 4 cable, hooked up
             BATT: 12.73 V
             Covered connectors, MUX, and BATT with plastic
.565  1333 MAG 4 TEMP: 23.82°C
           BATT: 14.52, 14.80, 13.15, 13.23 V
           TEMP: 35.2°C
           Samples @ 1499
           Weather: sunny and windy

 339   Dec  5, 1994
.454  1054 Fixed blue tarp, not covering green tarp
           Hit END, saved data
             Samples @ 4279
           TEMP: 33.6°C
           Used Kdisp6
             MAG 1,2,3,4: X-axis looks okay
             MAG 1, TEMP looks okay
             MAG 4, TEMP: duplexer working, data looks okay
           Computer time 09:58:38, actually 09:58:35
             Reset computer time

           (RB NOTE: PC time was accidentally set 1 hour early;
           it should have been 10:58:35; this error showed up in
           the data file)

.458  1059 Started KMGR
           BATT: 12.96, 13.45, 12.60, 12.85 V
           TEMP: 33.5°C
           Stopped KMGR
           Copied data to floppy
.463  1106 Started KMGR
.464  1108 Samples to 0, at second set of sub-samples
           Weather: windy, sunny
```

343 Dec 9, 1994

.553 1317 TEMP: 33.8°C
BATT: 13.39, 14.23, 12.76, 13.20 V
GRN/BLU wire: 1.544 V
Computer samples @ 2925, sub samples @ 30
All data values look reasonable
Duplexer BATT: 12.54 V

.558 1324 TEMP: 33.9°C, GRN/BLU: 1.559 V

.563 1330 TEMP: 33.9°C, GRN/BLU: 1.509 V
Opened Morris
HP100 screen:
-44 3431 3412 2187 2071 -769 75
Run MELDIAG:

MELDIAG DUTY	CYCLE	DISP TEMP	GRN/BLU VOLTS	OUTSIDE FAN
19	C	26.0°C	-2.343 V	ON
25	C	24.7	-2.959	
19	H	24.6	2.415	OFF
25	H	24.1	2.800	ON

Inside TE: 30.19°C
Outside TE: 21.08
Circuit Bd: 33.01
Ambient: 20.50

.566 1335 Run TEDCNT8
HP100 screen: 255 -1 3001 2718 1925 2071
Stable Rising Dropping Stable
TEMP: 27.8°C, GRN/BLU: 9.68 V
Closed Morris

.567 1337 TEMP: 29.5°C, GRN/BLU: 9.72 V, Outside fans on
All data values look reasonable

		TEMP	GRN/BLU	
.569	1340	31.4°C	9.79 V	
.571	1342	32.7	4.60	
.573	1345	32.9	2.93	
.574	1346	32.9	2.59,	Outside fans shut off
.575	1348	32.9	2.55	
.576	1350	32.9	2.49	
.578	1352	33.0	2.526	

Weather: windy, overcast, drizzling

.579 1354 TEMP: 32.9°C
Samples @ 2942, subsamples @ 504
TEMP MAG 4: 13.47°C

.581 1356 TEMP MAG 4: 21.21°C
TEMP: 32.9°C

```
 346   Dec 12, 1994
.442  1037 TEMP: 33.7°C
           Samples @ 4989, sub-samples @ 328
           Hit END, saved data
           Computer has 1.3 Mb free
           Copied data to floppy
           Computer time 08:30:52, actually 10:41:00
             Reset computer time
           **Note wrong computer time, same possible occurrence
             as on Nov 29. I thought Nov 29 might have been a
             fluke of mine from Nov 22, but now I think not**

           (RB NOTE: There are two "wrong computer times" here.
           The first is 1:10:08 noted above by Gary due to the
           KMGR program interrupts slowing the clock; the second
           is 1:00:00 which was due to the computer clock being
           set 1 hour early as noted on Dec. 5)

.447  1043 Started KMGR
           Data values look reasonable
           TEMP: 33.8°C
           BATT: 12.98, 13.56, 12.22, 12.76 V
.452  1051 Samples @ 3
           Left computer led light blinking, has lightbulb symbol
           Weather: partly cloudy, windy

 347   Dec 13, 1994
.615  1445 TEMP: 34.9°C (??)
           Computer date 12-12, time 14:33
             Samples @ 834, sub samples @ 447
           MAG 4 TEMP: 14.14°C,
              MAGs 1,2,3 TEMP: 20.69, 20.89, 23.41°C
           BATT: 14.44, 13.83, 12.40, 12.48 V
           Replaced BATT in 12 of 24 V system
           BATT: 14.00, 13.84, 12.76, 12.48 V
             Discovered reason 24 V system voltages dropping:
               Bottom 3 out of 4 24 V system solar panels in
                 shade from tree during afternoon
           TEMP: 34.9°C (Morris system TEMP. back to normal?)
           Computer date 12-12, time 14:45
             Time should read 14:57 if actual time
             Time seems to be advancing, but computer losing time
           Samples @ 840
           Weather: windy, clear
```

```
 350   Dec 16, 1994
.560   1327 Computer date: 12-12, time 12:45:13
            Samples @ 2939
            Fixed blue tarp, tie downs getting pulled out by wind
            TEMP: 34.2°C, BATT: 8.18 V
            Hit END, saved data
            Copied data to floppy
            Computer time 12:48:52, actually 13:30:10
              Reset time
.563   1331 Shut off main power to system
            BATT: 13.53, 14.56, 13.43, 13.83 V
            Duplexer BATT: 12.48 V
            Weather: windy, sunny
.574   1346 Turned main power on
            TEMP: 31.4°C
            Ran MELDIAG    CYCLES    OUTSIDE FANS
                             19   H      ON
                             25   H      ON
                             19   C      OFF
                             25   C      ON
            Ran TEDCNT8
              Display: 255   -1   3134   4025   2275   2383
            Closed Morris
.576   1350 TEMP: 32.4°C
            Ran chkdsk: 993K available on disk
            Deleted two Oct data files, now 2.3 Mb available
            TEMP: 33.8°C
            Ran KMGR with 1-second sample, data looks okay
.579   1354 Ran KMGR with 120-second sample
            MAG 1-4 TEMP: 20.48, 20.63, 22.96, 22.63°C
            MAG 1-4 Tot field: 32052, 32013, 31423, 32166 nT
            Display TEMP: 33.8°C
.582   1358 MAG 4 TEMP: 16.64°C
.583   1359 MAG 4 TEMP: 14.07°C
.583   1400 Data samples @ 2
            Display TEMP: 33.8°C
```

361 Dec 27, 1994
.452 1051 Display date 12-16
Display time 21:54:23
Display "Memory Full", samples @ 5999
TEMP. 34.3°C
Computer date 12-25-94, actually 12-27-94
Computer time 09:28:56, actually 10:52:20
Reset computer date & time
1.7M free disk space
.453 1053 Started KMGR
.455 1055 Stopped KMGR
Copied data to floppy
File Dec16m8m.dat, file creation date 12-25-94
BATT: 12.58, 13.61, 11.93, 12.41 V
.457 1058 Started KMGR
Panel for #3 BATT reads 12.00 V
TEMP 34.4°C
Removed brush shading panel
Wired extra solar panel to #3 BATT
#3 BATT: 12.31, panels read 12.60 V
.467 1112 MAG 4 TEMP 13.15°C , MAGs 1-3: 19.57, 19.78, 21.78°C
MAG 1-4 Total field: 32045, 32096, 31417, 32160 nT
.468 1114 Samples @ 7
MAG 4 TEMP 16.93°C
.469 1115 MAG 4 TEMP 21.73°C

368 Jan 3, 1995
.600 1424 Computer display date 12-27
Computer display time 13:11
Samples @ 5106
TEMP: 34.7°C
Saved data, copied to floppy
1.18 Mb free on computer
Computer time 13:16:31, actually 14:28:10
Reset time
Used KDISP6
MAG 1-4 X axis looks okay
MAG 4 TEMP okay, but data has odd crossing pattern between channels, looks like artifact of DAS
TEMP: 34.8°C
.606 1432 Started KMGR
All data values look ok
BATT: 12.63, 13.38, 13.55, 12.01 V
Switched solar panels on 24 V system, put 3 panels on weak BATT
BATTs 3 & 4: 13.22, 12.12 V
.612 1441 TEMP: 34.8°C
Weather: dry, overcast
Samples @ 4
MAG 4 TEMP was 13.02°C, now 21.69°C

374 Jan 9, 1995
.467 1112 TEMP: 34.6°C, BATT: 8.28 V
Computer display date 01-03
Computer display time 10:12:32
Samples @ 4189
.467 1113 Samples @ 4190, stopped program
Deleted Oct. data files
1.66 Mb free
BATT: 12.62, 13.09, 12.76, 14.08 V
Used KDISP6
MAG 1-4, X and Y axis looks okay
MAG 1 & 4 TEMP looks okay
Computer time 10:20:16, actually 11:19:00
Reset computer time
Actual time loss about 10 minutes per day
TEMP: 34.7°C
Copied Jan03 data to floppy
Switched solar panel banks for #3 & #4 BATTs
3 panels on #3 BATT, 2 panels on #4 BATT
.476 1126 Left computer alone, did not start KMGR
Weather clear & sunny

375 Jan 10, 1995
.412 0953 TEMP: 33.9°C
Computer time 09:53:43, actually 09:53:30
AST clock is running 13 seconds fast since yesterday
Reset AST clock
.413 0955 Started KMGR
MAG 1-4 TEMP: 18.32, 18.49, 20.09, 12.50°C
MAG 1-4 Total field: 32053, 32014, 31424, 32169 nT
BATT: 12.41, 12.86, 12.76, 12.75 V
Multiplexer BATT: 12.29 V
.417 1001 TEMP: 33.8°C
MAG 4 TEMP: 19.97°C
Weather: overcast
Water still dripping in cave, almost no rainfall in last 30 days
.419 1004 left site

```
 382   Jan 17, 1995
.556  1320 TEMP: 33.8°C
           No response from computer, screen dark
             One LED on, lightbulb symbol
           BATT: 12.90, 14.07, 15.36, 13.41 V
             (first BATT is for computer, seems a little low,
               maybe went too low for computer and caused problem
             weather is sunny now-
               may have been cloudy over the last week)
           Cycled computer power
           TEMP: 33.9°C
           Cannot see screen though adjusting contrast and light
           Reboot computer
             Now can see screen
             1.66 Mb free space
           Date okay
           Time 13:25:43, actually 13:26:00
             Reset time
.560  1327 Started KMGR
           MAG TEMPs 20.1°C - 22.3°C
           Total fields 31394 - 32021
.563  1330 TEMP: 34.1°C
.565  1334 TEMP: 34.1°C
           Samples @ 2
           Weather sunny & windy
             (8 inches of rain over last 7 days)
.567  1337 Computer lightbulb LED blinking
             LED that looks like a lock also on
           TEMP: 34.0°C
.568  1338 Samples @ 4
           left site
```

388	Jan 23, 1995	
.569	1339	TEMP: 35.1°C
		Computer screen 01-17, 12:37
		All data values look okay
		Samples @ 4296
		Saved data, 1.2 Mb free
		Copied data to floppy
		Deleted Jnk*.Dat, now 1.3 Mb free
		Used KDISP6
		MAG 1-4 X-axis looks okay
		MAG 1-4 TEMP looks okay
		Computer date okay
		Computer time 12:44:18, actually 13:45:30
		Reset computer time
.574	1347	Started KMGR
		TEMP: 35.2°C
		BATT: 13.60, 14.75, 15.63, 14.00 V
		Moved 3-panel array to first BATT (for computer)
.581	1356	MAG TEMPs: 19.6, 19.9, 21.3, 16.4°C
		MAG total fields: 32058, 32019, 31429, 32172 nT
		TEMP: 35.2°C
.581	1357	MAG 4 TEMP: 21.8°C
		Samples @ 4
		Weather: clear & sunny, winds 10 mph
395	Jan 30, 1995	
.598	1421	Hit computer keyboard, no response-stays dark
		Lightbulb LED is only one on
		Turned computer off
		Display TEMP 32.7°C
		BATT: 11.94, 13.10, 12.45, 11.67 V
		BATTs are low, probably why computer went out
		Weather is overcast
		Removed computer

```
 396   Jan 31, 1995
           Recharged AST computer at HVO
           Replaced low BATTs
           Run MELDIAG, 19 H - fans on
                        19 C - fans off
                        25 H - fans on
                        25 C - fans on ?
           Run TEDCNT8
             Screen reads: 255  -1  3017  4156  2143  2206
           Display TEMP: 28.2°C
.581  1356 TEMP: 30.2°C
           Set computer time
           Started KMGR with 2-second samples
             Data looks okay
           Started KMGR with 120 seconds/sample
           BATT: 13.14, 12.67, 13.19, 12.99 V
.588  1407 Samples @ 4
           TEMP: 30.3°C
           MAG TEMPs: 20.98, 21.29, 22.12, 20.31°C
           MAG total fields: 32052, 32013, 31424, 32167 nT
           Installed 10W solar panel for multiplexer BATT
.597  1420 TEMP: 30.4°C
           MAG TEMPs and total fields okay
           Samples @ 11
           Weather: raining

 402   Feb  6, 1995
.465  1109 Display date & time: 1-31, 10:10
             Data looks okay
             Samples @ 4206
           TEMP: 34.5°C
           Hit END, saved data
           BATT: 13.52, 13.42, 13.28, 13.20 V
           870K free on computer
           Copied data to floppy
           Used KDISP6
             MAG 1-4, X, Y, and TEMP look okay
           Computer date okay
           Computer time 10:15:58, actually 11:15:00
             Reset computer time
.469  1116 Started KMGR
           TEMP: 34.6°C
           All data looks okay
           Multiplexer BATT with panel: 12.74 V
                        BATT w/o panel: 12.69 V
.476  1125 Samples @ 3
           Weather: sunny, hazy
           Tube is very wet
```

409 Feb 13, 1995
.476 1126 Computer date: 02-06, time: 10:14:31
Samples @ 5008
Saved data
BATT: 12.61, 12.51, 12.56, 12.32 V
Display TEMP: 34.2°C
Copied data tp floppy
Computer time 10:19:17, actually 11:19:30
Reset computer time
Used KDISP6
MAG 1-4, x-axis looks okay
MAG 1 & 4 TEMP looks okay
.481 1133 Started KMGR
TEMPs: 18.91, 19.20, 20.61, 20.97°C
Total field: 32050, 32012, 31424, 32166 nT
Display TEMP 34.2°C
3-panel solar array on computer BATT
.483 1135 Computer date 2-13, time 11:35:06
Data values look okay
Samples @ 0
DAS BATTs have low indicator on
Weather: overcast, light wind

417 Feb 21, 1995
.478 1129 Display TEMP 34.6°C
Samples @ 5717, computer time 10:09:05
Saved data
BATT: 12.81, 13.01, 12.39, 11.86 V
Computer: 0 bytes free
Copied file to floppy, 348K (should be near 500K)
Deleted N*.* files, 1.7 Mb free
Used KDISP6
  MAG 1-4 X axis looks okay
  MAG 1 & 4 TEMP looks okay
Computer date okay
Computer time 10:15:37, actually 11:36:00
  Reset computer time
.484 1137 Started KMGR
TEMPs okay, total fields okay
Display TEMP 34.6°C
Duplexer BATT w/panel: 14.76 V
.487 1141 Samples @ 1
Data looks okay
Weather overcast
.603 1428 BATT: 12.45, 12.76, 12.04, 11.49 V
TEMPs and total fields look okay
Installed new BATTs for DAS
Switched fan and computer BATTs
BATT: 12.66, 12.57, 12.68, 12.74 V
Computer power glitched out during BATT switch
  Had to redo config file, used AST for password
  Hope all config settings are okay
.619 1452 Reset time on computer
Started KMGR
Display TEMP 33.6°C
Weather overcast, raining
MAG TEMPs: 20.2, 20.5, 21.8, 13.2°C
Total fields: 32058, 32020, 31430, 32173 nT
.623 1457 Samples @ 1

423	Feb 27, 1995	
.452	1051	Display TEMP: 34.8°C
		MAG TEMP and total fields look okay
		Samples @ 4168
		Saved data
		BATT: 13.87, 13.21, 13.44, 13.32 V
		Copied data to floppy
		Used KDISP6
		MAG 1-4, X,Y,Z, & TEMP look okay
		All MAG axes look a little too smooth for first 2000 pts
.458	1059	Computer time 10:00:09, watch=10:58:48
		Reset computer time
		Computer has 1.27 Mb free
.458	1100	Started KMGR
		Display TEMP: 34.9°C
		Data: total field and TEMP look okay
		Samples @ 0
		Weather: clear & sunny
.463	1106	Samples @ 2
430	Mar 6, 1995	
.467	1113	Display TEMP: 35.3°C
		All data values look okay
		Samples @ 5011
		Saved data
		BATT: 14.06, 14.57, 13.59, 13.37 V
		Computer has 749K free
		Copied Feb21m8m.dat and Feb27m8m.dat to floppy
		Computer date okay
		Computer time 10:08:52, actually 11:19:00
		Reset computer time
		Used Kdisp6
		MAG 1-4, X, Y Z, T look okay
.475	1124	Started KMGR
		Display TEMP: 35.3°C
		MAG TEMPs 20.5 - 22.68°C
		Total fields: 32046, 32007, 31417, 32161 nT
.478	1129	All data values look okay
		Samples @ 1
		Weather: clear, sunny, light wind

437	Mar 13, 1995	
.583	1400	Display TEMP 34.9°C
		Samples @ 5082
		Tried copying data to floppy, not enough space
		Tried copying data to second floppy, can't read floppy
		Reformatted floppy
		Copied data to floppy
		219K free space
		BATT: 12.67, 13.37, 12.39, 12.28 V
		Deleted December data from computer, 2.2 Mb free
		Computer date okay
		Computer time 12:55:02, actually 14:07:00
		Reset computer time
.589	1408	Started KMGR
		MAG TEMPs okay, total fields okay
		Weather overcast
		Samples @ 0
439	Mar 15, 1995	
.449	1047	Display TEMP 35.0°C
		MAG TEMPs and total field okay
		Samples @ 1329
		BATT: 13.28, 14.40, 12.72, 12.62 V
		Replaced DAS BATTs
		BATT: 12.93, 13.74, 13.54, 13.69 V
		Weather overcast
.467	1113	Replaced computer BATT, now 15.11 V (with sun)
		MAG TEMPs 20.53 - 22.71°C
		Total fields: 32052, 32014, 31434, 32168 nT
		Display TEMP 35.1°C
.469	1115	Weather sunny

441	Mar	17, 1995
.389	0920	Display TEMP: 34.4°C
		Samples @ 2715
		All data values look okay
		Stopped KMGR, saved data
		BATT: 13.27, 13.26, 13.25, 13.40 V
		1.9 Mb free
.390	0922	Started Mar17R1, 286 samples, data values look okay
		Rotated TESSA, MAG 2 on top
.398	0933	Started Mar17R2, 321 samples, "
		Rotated TESSA, MAG 3 on top
.403	0940	Started Mar17R3, 332 samples, "
		Rotated TESSA, MAG 4 on top
.408	0947	Started Mar17R4, 321 samples, "
		Rotated TESSA, MAG 1 on top
.413	0955	Started Mar17R1B, 322 samples, "
		Lifted TESSA, reset TESSA
.417	1000	Started Mar17R1C, 326 samples, "
		Rotated TESSA, MAG 4 on top
.424	1010	Started Mar17R4B, 315 samples, "
		Tetrahedron level bubbles okay
		Northern level bubble is at line, but not outside
		Display TEMP 34.9°C
.425	1012	Copied March files to floppy
.426	1014	Computer date okay
		Computer time 09:36:03, actually 10:14:15
		Reset computer time
		1.67 Mb free
.427	1015	Started KMGR
		MAG TEMPs: 19.74, 19.87, 21.47, 13.47°C
		Total fields: 31655, 31787, 31958, 32351 nT
		MAG 4 is on top of tetrahedron, MAG 3 to north
		Weather is partly sunny
.428	1017	Samples at 0

```
        (RB NOTE: The digital notes from Mar 20 were lost.
        The following has been retyped from a paper copy)

 444   Mar 20, 1995
.563  1331 Display TEMP: 35.2°C
           MAG TEMP and total field values look okay
           Samples @ 2241
           Saved data, 1.4 Mb free
           BATT: 15.44, 15.08, 15.39, 15.26 V
           Copied data to floppy
           Computer time 13:02:31, actually 13:33:53
             Reset computer time
           Used KDISP6
             All MAGs, all axis look okay, no obvious problems
             All TEMPs look okay
.568  1338 Started KMGR
           MAG TEMPs 21.0 - 23.79°C
           MAG total fields: 31660, 31795, 31965, 32360 nT
           Display TEMP 35.2°C
           Weather: sunny & windy
.572  1343 Samples @ 1
           Data looks okay

 451   Mar 27, 1995
.593  1414 Display TEMP: 34.9°C
           Samples @ 5021
           MAG TEMPs and total fields okay
           Saved data, 900K free
           Copied data to floppy
           BATT: 13.96, 14.71, 13.54, 13.03 V
           Computer date okay
           Computer time 13:08:36, actually 14:19:00
             Reset computer time
           Used KDISP6
             Everything working, although X-axis on all MAGs has
               very low deviation for first 2000 points, good
               deviation after that
.600  1424 Started KMGR
           Display TEMP 34.7°C
           All data values look okay
           Weather overcast, windy
```

```
 455    Mar 31, 1995
.400   0936 Samples @ 2716, data values look reasonable
            Display TEMP: 33.3°C, BATT: 7.94 V
            BATT: 13.57, 13.50, 13.50, 13.33 V
.402   0939 Display TEMP: 33.5°C
.403   0941    "    "    33.6
.406   0944    "    "    33.8  , weather sunny & windy
.408   0947    "    "    34.0
.413   0954    "    "    34.2
            MAG TEMP: 19.7, 20.0, 21.6, 22.1°C
            MAG total field: 31676, 31809, 31980, 32375 nT
.417   1001 Stopped KMGR, 506K free
            Started KMGR, Mar31T1.dat with 0.2sec/sampling
              Lifted TESSA +1 foot for 10 seconds
              Reset TESSA
            (MAG 4 on top, MAG 1 to left, MAG 2 to right,
              MAG 3 at far point
              Standing at back of TESSA looking out to skylight)
.422   1007 Stopped KMGR, 1225 samples
            Computer time 09:30:02, actually 10:08:22
              Reset time
.423   1009 Display TEMP: 34.3°C
.424   1010 Started KMGR
              MAG TEMP and total fields look okay
            Display TEMP: 34.4°C
.424   1011 Disconnected TED power
.426   1013 Display TEMP: 34.5°C
              TEMP still climbing, reconnected TED power
            Opened Morris
              HP display: -48 3218 3325 2275 2696
               couple seconds later
              HP display: 255 -1 3181 4550 2012 2696
              Display TEMP: 28.8°C
            Closed Morris
            Outside fans on (haven't heard this in a long time)
.428   1017 Display TEMP: 33.9°C
.429   1018    "    "    34.3
            Outside fans off (at 10:18:50)
.431   1020 Display TEMP: 34.6
.432   1022 Samples @ 4
            Display TEMP: 34.5
.435   1026    "         34.5
.436   1028    "         34.4,
                         MAG TEMPs: 19.81, 20.13, 21.70, 13.28°C
                         MAG tot flds: 31678, 31814, 32378 nT
                         Samples @ 8
.439   1032    "         34.4
.442   1036 Opened Morris again
             HP: -13 3497 3325 2318 2891 555 402
              couple seconds later
             HP: 255 -1 3229 4156 2100 2872
.442   1037 Closed Morris
            Display TEMP: 33.6°C
            Outside fans on
```

455 Mar 31, 1995 (continued)
.443 1038 Display TEMP: 34.1°C,
MAG TEMP: 19.83, 20.15, 21.75, 13.45°C
MAG tot flds: 31682,31810,31988,32382 nT
.444 1039 " 34.6°C, outside fans off
.444 1040 " 34.7
.446 1042 " 34.8/34.7, samples @ 11, data same as 1038
.447 1043 " 34.6
.448 1045 " 34.5, total flds: 31681, 31818, 31987, 32382

458 Apr 3, 1995
.444 1040 Display TEMP: 35.0°C
Data values look okay, samples @ 2159
Saved data
282K free
Computer time 10:11:50, actually 10:41:54
Turned off computer
Dismantling site
Levels on TESSA okay
Long level touching one line
Short level balanced
Proton MAG @ MAG 3 position: 32155
@ MAG 2 position: 32216
@ MAG 1 position: 32222
@ MAG 4 position: 32125 (top of TESSA)
@ center of TESSA: 32192
on floor under TESSA: 32349
1 m above TESSA: 32205
Dismantled TESSA
Had problems removing legs, wood has swelled due to moisture
Some metal spacers have fallen off TESSA-glue failed
Plywood pieces started to delaminate
left site at 1330

APPENDIX C. SHIPPING LISTS OF EQUIPMENT

TMGS-EQUIPMENT CHECKLIST:

__ 1 TESSA (use vertex protectors when MAGs not installed)
__ 4 Vertex protectors (plywood triangles)
__ 12 brass bolts (same hardware as was used for attaching vertex plates)
__ 12 brass nuts (" " " " " " " " ")
__ 24 brass washers (" " " " " " " " ")
__ 4 Corian vertex plates (white)
__ 4 Velcro straps
__ 4 Bakelite cable clamps (for routing MAG cables around vertex plates)
__ 4 MAGs (in grey plastic boxes)
__ 3 Boxes of brass mntg hardware (bolts/nuts/washers) for MAGs, plates, & scopes
__ 4 MAG cables
__ 4 Bundling velcro straps
__ 4 White wooden MAG covers

__ 1 Upper base platform
__ 1 Bubble-level on front side of upper base platform
__ 1 Bubble-level on back side of upper base platform
__ 2 Plywood scope mounts on the upper base platform
__ 1 Lower base platform
__ 3 Brass leveling bolts & locking strips on lower base platform
__ 2 scopes for aligning platform with survey marks

__ 1 TESSA clamp (round wooden with 3 protrusions)
__ 1 TESSA clamp threaded rod (yellow, foot long)
__ 1 TESSA clamp tightening nut (wooden, oval)
__ 1 TESSA clamp gimbling washer (wooden, round)
__ 1 TESSA clamp pressure plate (wooden, irregular shaped)
__ 1 TESSA clamp set screw (round wooden handle w/yellow threaded section)

__ 1 Sedan (large wooden framework)
__ 4 Sedan carrying rods (2x2 wooden about 4 feet long)
__ 5 Sedan legs (3 long, 1 medium, 1 short)
__ 3 Wooden leg pins for sedan
__ 1 Large elastic shock cord for sedan leg tightening

__ 1 Morris (big grey plastic with heat sink).
__ 1 HP palm-top computer
__ 1 HP RS232 cable & flat conversion for interconnect
__ 1 12-V power converter (for the AST) w/battery clips
__ 1 115vac power converter (for the AST) w/wall-power cable
__ 1 RS232 cable (flat, long)
__ 1 RS232 cable (round, white, w/screw-on interconnects)
__ 1 Connector cable for the Morris temperature display unit

__ 1 Grey jumper cable for the main 12/24-V batteries
__ 1 Power supply for Morris
__ 1 Temperature display unit

__ 1 AST laptop computer
__ N 3 1/2" disks for storing data

__ 1 Red cart main body (2 of the 4 handle screws and nuts included; the other screws and nuts for all other attachments go elsewhere)
__ 1 Cart handle
__ 2 Cart legs
__ 1 Wooden anti-sink 2x4 for the cart legs (about 2 or 3 feet long)
__ 1 Cart tire assembly (2 tires, 1 axle, and 1 red mounting bracket)
__ 1 Cart liner (cardboard insert)
__ 2 Plywood platforms for the top of the cart
__ N Bolts and Nuts for Cart assembly

__ 1 Base Magnetometer system assembly

APPENDIX D. DATA ACQUISITION PROGRAM

```
/* KMGR.C  provides an interface to the 4 MAG, 16 bit DAS.  It will       */
/* accept operator input for a file name and comment. The program will    */
/* display field components and total fields for 4 magnetometers.  One    */
/* file can be produced for each time the program is run. It will fill    */
/* s=data records at a 5 Hz rate or display one sample of MAG field data. */
/* Compile using the huge memory model.                                   */
/* last update: 22 Nov '93  - modify file name entry, add DAS             */
/*                                     */
/* PROGRAM KMGS WRITTEN BY TOM GROVER, U.S. GEOLOGICAL SURVEY             */
/*   kmgs9 modifications 11 Jun 94  */
/* PROGRAM KMGR MODIFIED FROM KMGS BY ROB BRACKEN, U.S. GEOLOGICAL SURVEY */
/*   kmgr modifications  11 Nov 94  */

#include <dos.h>
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include <stdlib.h>

/*                     global variables                                   */
int k, DAS;             /* gen'l purpose counting var, boolean for DAS    */
char buf[80];           /* gen'l purpose string var                       */
int nsamp;              /* number of data records                         */
int tsamp;              /* seconds per sample 1 thru 999 or 0.2           */
int status;             /* comm status var, timeout status var            */
unsigned char *dptr[6000];      /* array of pointers to data records      */
FILE *fout;             /* output file handle                             */
char fname[13];         /* output file name                               */
char comment[65];       /* file header comment                            */
union REGS regs;        /* 80x86 registers for BIOS calls                 */
struct time ts, startts;        /* time structure for gettime fctn        */
struct date ds;         /* date structure for getdate fctn                */
int bin0[3];            /* bin numbers for MAG 0  x,y,z axis              */
int bin1[3], bin2[3], bin3[3];
float volt0[3];         /* calculated DAS output voltage values, 16 chan  */
float volt1[3], volt2[3], volt3[3];
int nsub;               /* sub sample counter for averaging procedures    */
unsigned char abuf[48]; /* data buffer array for averaging procedures     */
double dsum[16];        /* array for summing data for averaging procedures*/

/*  calibration values for the bin constants x,y,z for 4 magnetometers    */
float cal0[]={ 500.0, 500.0, 500.0 };
float cal1[]={ 500.0, 500.0, 500.0 };
float cal2[]={ 327.0, 327.0, 327.0 };
float cal3[]={ 327.0, 327.0, 327.0 };
/*  calibration values for the zero offsets x, y, z for 4 magnetometers   */
float zofs0[]={   62.6,   76.8,   14.9 };
float zofs1[]={   84.7,   34.6,   -0.9 };
float zofs2[]={  208.5,  -43.6,  -22.5 };
float zofs3[]={ -210.1,   -3.6,   11.4 };

/*                      Procedures                                        */
void UpdateFilename(void);      /* enter the data file name               */
```

```
void UpdateComment(void);       /* enter a comment for the data file        */
void UpdateSampleTime(void);    /* enter the sample rate                     */
void BuildMain(void);   /* write the main screen                             */
void GetData(void);     /* read one sample from DAS for screen update        */
void AvgOpen(void);     /* initialize buffer for sub-sample accumulation     */
void AvgSum(void);      /* read a sub-sample from DAS & add to summation     */
void AvgClose(void);    /* divide data summation by number of sub-samples */


void SaveData(void);    /* create data file                                  */
void ShowData(void);    /* calculate fields & write data to screen           */
void FillRecord(void);  /* 5 Hz rate, no screen update                       */
void FakeRecord(void);  /* no DAS, fill record with zeros                    */

/*            comm subroutines use BIOS intr 0x14 and REGS union            */
unsigned int Init232(void);              /* initialize the serial port      */
unsigned int Transmit(unsigned char);    /* send one char                    */
unsigned int Receive(void);              /* receive one char                 */
unsigned int GetStatus(void);            /* read the status word             */

/* Initialize: get comment & filename, cleanout rs232 buffer, allow exit  */
void main(void){
int quit, done;
long currtime, endtime;
char key;

   DAS=0;                 /* use for debugging */
   if ( DAS ) { status=GetStatus() & 0x0020; }
   else status=1;
   if ( !status ){
      printf("DAS is not ready!\n\r");
      printf("Program is terminated\n\r");
      return;
      }
   UpdateFilename();
   UpdateSampleTime();
   UpdateComment();
   if ( DAS ){    Init232();
      Transmit('D');   delay(100);
      status=GetStatus() & 0x0100;
      while (status) { Receive(); status=GetStatus() & 0x0100; }
      }
   nsamp=0;  quit=0;
   BuildMain();  _setcursortype(0);
   while (!quit){
      if ( nsamp>=5999 ) { gotoxy(15,4);
         cputs("Memory is full - Save it or Clear it");
         }
      key=toupper( getch() ); if (!key) getch();
      switch(key){
      case 'U' : {
         nsub=0;
         GetData();
         ShowData();
         nsamp++;
         break; }
```

```
case 'F' : {
   gotoxy(5,3); putch('U');  gotoxy(20,3);  putch('F');
   gotoxy(35,3);  putch('C'); gotoxy(50,3);  putch('S');
   gotoxy(65,3);  putch('Q');
   done=0;
   gettime( &startts );
   for ( k=0; k<nsamp; k++) free( dptr[k] );
   nsamp=0;
   gotoxy(15,4);
   cputs("Filling RAM - press END to quit ");
   if ( tsamp==0 ){
      nsub=0;
      if ( DAS ) Transmit('E');
      while ( !done && nsamp<6000 ) {
         if ( DAS ) FillRecord();
         else FakeRecord();
         gotoxy(15,20); cputs("     ");
         gotoxy(15,20); cprintf("%4d",nsamp);
         nsamp++;
         if ( kbhit() ) {
            key=getch();
            if ( !key ) key=getch();
            else key=0;
            }
         if ( key==0x4F ) done=1;
         }
      }
   else while ( !done && nsamp<6000 ){
      gettime( &ts );
      /* getdate( &ds ); */
      currtime=(long)ts.ti_sec;
      currtime+=60*(long)ts.ti_min;
      /* currtime+=3600*(long)ts.ti_hour; */
      /* currtime+=86400*(long)ds.da_day; */
      endtime=currtime+(long)tsamp;
      /* nsub=0; */
      /* GetData(); */
      AvgOpen();

      gotoxy(25,20); cputs("              ");
      gotoxy(25,20);  puts("Sub-Sample #");
      gotoxy(39,20); cputs("     ");
      gotoxy(39,20); cprintf("%4d",nsub);

      while ( !done && currtime<endtime ) {
         gettime( &ts );
         /* getdate( &ds ); */
         currtime=(long)ts.ti_sec;
         currtime+=60*(long)ts.ti_min;
         /* currtime+=3600*(long)ts.ti_hour; */
         /* currtime+=86400*(long)ds.da_day; */
         if ( endtime-currtime > 1800 ) currtime+=3600;
         AvgSum();
         gotoxy(39,20); cputs("     ");
         gotoxy(39,20); cprintf("%4d",nsub);
         if ( kbhit() ){
```

```
                key=getch();
                if ( !key ) key=getch();
                else key=0;
                }
             if ( key==0x4F ) done=1;
             }
          AvgClose();
          ShowData();
          nsamp++;
          }
       if ( DAS ){
          Transmit('D');     delay(100);
          status=GetStatus() & 0x0100;
          while (status) { Receive();
             status=GetStatus() & 0x0100; }
          }
       gotoxy(15,4);
       cputs("                                    ");
       highvideo();
       gotoxy(5,3); putch('U');  gotoxy(20,3);  putch('F');
       gotoxy(35,3);  putch('C'); gotoxy(50,3);  putch('S');
       gotoxy(65,3);  putch('Q');  normvideo();
       break;
       }
    case 'C' : {
       if ( DAS ){
          Transmit('D');  delay(100);
          status=GetStatus() & 0x0100;
          while (status) { Receive();
             status=GetStatus() & 0x0100; }
          }
       for (k=0; k<nsamp; k++) free(dptr[k]);
       nsamp=0;
       BuildMain();
       break;
       }
    case 'S' : {
       if ( DAS ){
          Transmit('D');  delay(100);
          status=GetStatus() & 0x0100;
          while (status) { Receive();
             status=GetStatus() & 0x0100; }
          }
       gotoxy(15,4);
       cputs("                                    ");
       gotoxy(15,4);  cputs("Saving Data");
       SaveData();
       quit=1;
       break;
       }
    case 'Q' : {
       if ( DAS ) Transmit('D');
       quit=1;
       }
    }  /* end switch case(key) */
 }  /* end if !quit */
```

```
   clrscr();  _setcursortype(2);
   return;
   }


void UpdateFilename(void){
int nameOK;
   clrscr();
   gotoxy(20,2); cputs("KMGR   Setup Data Entry");
   gotoxy(5,4); cputs("Enter a filename and file comment");
   gotoxy(40,4); cputs("or just press enter to use the defaults:");
   gotoxy(3,5);  cputs("filename = KMGRTEST.DAT, comment is blank,");
   gotoxy(45,5);  cputs("and sample time is 0.2 sec/sample");
   gotoxy(5,8);  cputs("Filename");
   gotoxy(40,8);  cputs("DAT extension added automatically");
   gotoxy(5,12);  cputs("Comment");  gotoxy(5,10);
   cputs("1 to 999 Seconds per Sample");
   nameOK=0;
   while ( !nameOK ) {
      buf[0]=9;  gotoxy(15,8);  cputs("              ");
      gotoxy(15,8);  cgets(buf);
      if ( buf[1]==0 ) strcpy(buf,"KMGRTEST");
      else    for (k=0; k<9; k++) buf[k]=toupper( buf[k+2] );
      nameOK=1;
      for ( k=0; k<strlen(buf); k++ ){
         if ( buf[k]<'0' ) nameOK=0;
         if ( buf[k]>'Z' ) nameOK=0;
         if ( (buf[k]<'A') && (buf[k]>'9') ) nameOK=0;
         }
      strcat(buf,".DAT");
      gotoxy(15,8);  cputs("              ");
      gotoxy(15,8);  cputs(buf);
      fout = fopen( buf,"r" );
      if ( fout!=NULL ) nameOK=0;
      fclose( fout );
      if ( !nameOK ){   gotoxy(20,7);
         cputs("Use A-Z, 0-9 only!    or    Name in Use");
         delay(3000);    gotoxy(20,7);
         cputs("                                        ");
         }
      }
   strcpy(fname,buf);
   return;
   }

void UpdateSampleTime( void ){
   buf[0]=4;
   gotoxy(33,10);  cgets(buf);
   if ( buf[1]==0 ){
      gotoxy(33,10);  cputs("0.2 Seconds/sample");
      tsamp=0;
      return;
      }
   for ( k=0; k<6; k++ ) buf[k]=buf[k+2];
   tsamp=atoi( buf );
   if ( (tsamp>999) || (tsamp<1) ){
```

```
      gotoxy(34,10);  cputs("Invalid input");
      delay(3000);
      gotoxy(34,10);  cputs("0.2 Seconds/sample");
      tsamp=0;
      }
   else {
      gotoxy(33,10);  cprintf("%4d",tsamp);
      gotoxy(39,10);  cputs("Seconds per sample");
      }
   return;
   }

void UpdateComment( void ){
   buf[0]=61;
   sprintf(comment,"%03d",tsamp);
   strcat(comment," ");
   gotoxy(5,13);  cgets(buf);
   for ( k=0; k<80; k++ ) buf[k]=buf[k+2];
   strcat(comment,buf);
   for ( k=strlen(comment); k<64; k++ ) comment[k]=' ';
   comment[64]='\0';
   gotoxy(5,13); cputs(comment);
   delay(3000);
   return;
   }

void BuildMain(void){
   clrscr();
   gotoxy(30,2);  puts("KMGR   Main Menu");
   gotoxy(5,3);  puts("Update");  gotoxy(20,3);  puts("FillRAM");
   gotoxy(35,3); puts("Clear Mem"); gotoxy(50,3); puts("Save Data");
   gotoxy(65,3);  puts("Quit-No Save");
   highvideo();    gotoxy(5,3); putch('U');  gotoxy(20,3);  putch('F');
   gotoxy(35,3);  putch('C');  gotoxy(50,3);  putch('S');
   gotoxy(65,3);  putch('Q');  normvideo();
   gotoxy(5,5);  puts("File:");  gotoxy(30,5);  puts("Date:");
   gotoxy(45,5);  puts("Time:");   gotoxy(5,20);  puts("Sample #");
   gotoxy(5,6);  puts("Comment:");  gotoxy(14,6);  puts(comment);
   gotoxy(5,8);  puts("Mag    X bin   volts       Y bin   volts");
   gotoxy(52,8); puts("Z bin   volts     Temperature");
   gotoxy(5,14); puts("Mag    X field         Y field      Z field");
   gotoxy(57,14);  puts("Total Field");
   gotoxy(65,5);  cputs("Sec/Sample");
   if ( tsamp>0 ){
      gotoxy(76,5);  cprintf("%3d",tsamp);
      }
   else {
      gotoxy(76,5); cputs("0.2");
      }
   for (k=1; k<5; k++){
      gotoxy(7,8+k);  cprintf("%1d",k);
      gotoxy(7,14+k);  cprintf("%1d",k);
      }
   getdate( &ds );
   gotoxy(37,5); cprintf("%02d",ds.da_mon);
   gotoxy(39,5); putch('-');
```

```
   gotoxy(40,5); cprintf("%02d",ds.da_day);
   gotoxy(12,5);  cputs(fname);
   return;
   }

void GetData(void){
   if ( nsamp>=5999 ) return;
   if ( DAS ){
      Transmit('E');
      FillRecord();
      Transmit('D');
      delay(100);
      status=GetStatus() & 0x0100;
      while ( status ) { Receive();
         status=GetStatus() & 0x0100; }
      }
   else FakeRecord();
   return;
   }

void SaveData(void){
int n;
char fstr[17];
   fout=fopen(fname,"wb");
   strcpy(fstr,"KMGR data       ");
   getdate(&ds);
   sprintf(buf,"%02d",ds.da_mon);
   fstr[10]=buf[0];  fstr[11]=buf[1];
   sprintf(buf,"%02d",ds.da_day);
   fstr[13]=buf[0];  fstr[14]=buf[1];
   for (k=0; k<16; k++) fputc( fstr[k],fout );
   strcpy(fstr,"  :  :  ");
   sprintf(buf,"%02d",startts.ti_hour);
   fstr[0]=buf[0];  fstr[1]=buf[1];
   sprintf(buf,"%02d",startts.ti_min);
   fstr[3]=buf[0];  fstr[4]=buf[1];
   sprintf(buf,"%02d",startts.ti_sec);
   fstr[6]=buf[0];  fstr[7]=buf[1];
   for (k=0; k<8; k++) fputc(fstr[k],fout);
   for (k=0; k<64; k++)  fputc( comment[k], fout );
   for (n=0; n<nsamp; n++) {
      sprintf(buf,"%04d",n);
      fputc('\n',fout);  fputc(' ',fout);
      for (k=0; k<4; k++) fputc(buf[k],fout);
      fputc(' ',fout);  fputc(' ',fout);
      for (k=0; k<48; k++) {
         sprintf(buf,"%02X", *(dptr[n]+k) );
         fputc(buf[0],fout);  fputc(buf[1],fout);
         }
      }
   fclose(fout);
   return;
   }

void ShowData(void){
unsigned int inp;
```

```
float fld0[3], fld1[3], fld2[3], fld3[3];
double tot, temp;
float vtemp;
   for (k=0; k<3; k++){
      inp=( *(dptr[nsamp]+ 1+k*3)<<8 ) + *(dptr[nsamp]+ 2+k*3);
      volt0[k]=0.0002*(float)( inp-32768 );
      inp=( *(dptr[nsamp]+13+k*3)<<8 ) + *(dptr[nsamp]+14+k*3);
      volt1[k]=0.0002*(float)( inp-32768 );
      inp=( *(dptr[nsamp]+25+k*3)<<8 ) + *(dptr[nsamp]+26+k*3);
      volt2[k]=0.0002*(float)( inp-32768 );
      inp=( *(dptr[nsamp]+37+k*3)<<8 ) + *(dptr[nsamp]+38+k*3);
      volt3[k]=0.0002*(float)( inp-32768 );
      bin0[k]=*(dptr[nsamp]+ 0+k*3);
      bin0[k]-=(0x0100>>k)*( *(dptr[nsamp]+ 9) & (0x01<<k) );
      bin1[k]=*(dptr[nsamp]+12+k*3);
      bin1[k]-=(0x0100>>k)*( *(dptr[nsamp]+21) & (0x01<<k) );
      bin2[k]=*(dptr[nsamp]+24+k*3);
      bin2[k]-=(0x0100>>k)*( *(dptr[nsamp]+33) & (0x01<<k) );
      bin3[k]=*(dptr[nsamp]+36+k*3);
      bin3[k]-=(0x0100>>k)*( *(dptr[nsamp]+45) & (0x01<<k) );
      fld0[k]=(float)bin0[k] *cal0[k]- zofs0[k] +volt0[k]*100.0;
      fld1[k]=(float)bin1[k] *cal1[k]- zofs1[k] +volt1[k]*100.0;
      fld2[k]=(float)bin2[k] *cal2[k]- zofs2[k] +volt2[k]*100.0;
      fld3[k]=(float)bin3[k] *cal3[k]- zofs3[k] +volt3[k]*100.0;
      }
   for (k=0; k<3; k++){
      gotoxy(12+k*20,9);  cputs("    ");
      gotoxy(12+k*20,9);  cprintf("%4d",bin0[k]);
      gotoxy(12+k*20,10);  cputs("    ");
      gotoxy(12+k*20,10); cprintf("%4d",bin1[k]);
      gotoxy(12+k*20,11);  cputs("    ");
      gotoxy(12+k*20,11); cprintf("%4d",bin2[k]);
      gotoxy(12+k*20,12);  cputs("    ");
      gotoxy(12+k*20,12); cprintf("%4d",bin3[k]);
      gotoxy(20+k*20,9);  cputs("       ");
      gotoxy(20+20*k,9);   cprintf("%7.4f",volt0[k]);
      gotoxy(20+k*20,10);  cputs("       ");
      gotoxy(20+20*k,10);  cprintf("%7.4f",volt1[k]);
      gotoxy(20+k*20,11);  cputs("       ");
      gotoxy(20+20*k,11);  cprintf("%7.4f",volt2[k]);
      gotoxy(20+k*20,12);  cputs("       ");
      gotoxy(20+20*k,12);  cprintf("%7.4f",volt3[k]);
      gotoxy(12+k*20,15);  cputs("       ");
      gotoxy(12+k*15,15);  cprintf("%7.1f",fld0[k]);
      gotoxy(12+k*20,16);  cputs("       ");
      gotoxy(12+k*15,16);  cprintf("%7.1f",fld1[k]);
      gotoxy(12+k*20,17);  cputs("       ");
      gotoxy(12+k*15,17);  cprintf("%7.1f",fld2[k]);
      gotoxy(12+k*20,18);  cputs("       ");
      gotoxy(12+k*15,18);  cprintf("%7.1f",fld3[k]);
      }
   temp=fld0[0]*fld0[0]+fld0[1]*fld0[1]+fld0[2]*fld0[2];
   tot=sqrt(temp);  gotoxy(57,15);  cputs("        ");
   gotoxy(57,15);  cprintf("%6.1f",tot);
   temp=fld1[0]*fld1[0]+fld1[1]*fld1[1]+fld1[2]*fld1[2];
   tot=sqrt(temp);  gotoxy(57,16);  cputs("        ");
```

```
    gotoxy(57,16);  cprintf("%6.1f",tot);
    temp=fld2[0]*fld2[0]+fld2[1]*fld2[1]+fld2[2]*fld2[2];
    tot=sqrt(temp);  gotoxy(57,17);  cputs("        ");
    gotoxy(57,17);  cprintf("%6.1f",tot);
    temp=fld3[0]*fld3[0]+fld3[1]*fld3[1]+fld3[2]*fld3[2];
    tot=sqrt(temp);  gotoxy(57,18);  cputs("        ");
    gotoxy(57,18);  cprintf("%6.1f",tot);
    gotoxy(15,20);  puts("     ");
    gotoxy(15,20);  cprintf("%4d",nsamp);
    for ( k=0; k<4; k++){
       inp=( *(dptr[nsamp]+10+k*12)<<8 ) + *(dptr[nsamp]+11+k*12);
       vtemp=0.002*(float)( inp-32768 );
       gotoxy(71,9+k);  puts("      ");
       gotoxy(71,9+k);  cprintf("%5.2f",vtemp);
       }
    gettime( &ts );
    gotoxy(51,5);  cputs("  :  :  ");
    gotoxy(51,5);  cprintf("%02d",ts.ti_hour);
    gotoxy(54,5);  cprintf("%02d",ts.ti_min);
    gotoxy(57,5);  cprintf("%02d",ts.ti_sec);
    gotoxy(37,5); cprintf("%02d",ds.da_mon);
    gotoxy(39,5); putch('-');
    gotoxy(40,5); cprintf("%02d",ds.da_day);
    return;
    }

unsigned int Init232(void) {
regs.h.ah=0;             /* initialize comm port */
regs.h.al=0xc3;          /* 4800 baud, 8 data, 1 stop, no parity  */
regs.x.dx=0;             /*  comm port 1  */
int86( 0x14, &regs, &regs );
return regs.x.ax;
}

unsigned int Transmit( unsigned char dat ){
regs.h.ah=1;             /* send one character */
regs.h.al=dat;           /* char to send */
regs.x.dx=0;             /* comm port 1 */
int86( 0x14, &regs, &regs );
return regs.x.ax;
}

unsigned int Receive(void){
regs.h.ah=2;             /*  read input buff register */
regs.x.dx=0;             /* comm port 1 */
int86( 0x14, &regs, & regs );
return regs.x.ax;        /* data in al, status in ah */
}

unsigned int GetStatus(void){
/* 0100-RxRdy 2000-TBE 0e00-err 0080-DCD 0020-DSR 0010-CTS  */
regs.h.ah=3;             /* get status word */
regs.x.dx=0;             /* comm port */
int86( 0x14, &regs, &regs );
return regs.x.ax;
}
```

```
/*
ORIGINAL FILLRECORD PROCEDURE
void FillRecord( void ){
   dptr[nsamp] = malloc(48);
   for ( k=0; k<48; k++){
      status=0;
      while ( !status ) status=GetStatus() & 0x0100;
      *(dptr[nsamp]+k)=( unsigned char )( Receive() & 0x00ff );
      }
   return;
   }
*/

void FillRecord( void ){
long currtime, endtime;
int mxerr;
int jerr;
int ndur;
/*
   ALLOCATE 48 UNSIGNED CHAR SPACES (1 BYTE) FOR DATA STORAGE */
   dptr[nsamp] = malloc(48);
/*
   ESTABLISH MAX# OF READ ATTEMPTS BEFORE ASSIGNING DUMMY VALUES */
   mxerr=2;
   if(tsamp == 0) mxerr=1;
/*
   ESTABLISH DURATION OF TIME-OUT WINDOW IN HUNDREDTHS OF A SECOND */
   ndur=40;
   if(tsamp == 0) ndur=30;
/*
   READING ATTEMPT LOOP */
   for ( jerr=0; jerr<mxerr; jerr++){
/*
      SET UP TIME-OUT WINDOW FOR CURRENT READ ATTEMPT */
      gettime( &ts );
      currtime=(long)ts.ti_hund;
      endtime=currtime+(long)ndur;
/*
      LOOP FOR READING DATA CHARACTERS FROM RS232 REGISTER */
      for ( k=0; k<48; k++){
/*
         HOLD IN SUB-LOOP UNTIL A CHARACTER APPEARS IN THE REGISTER */
         status=0;
         while ( status==0 && currtime<endtime ){
/*
            UPDATE THE CURRENT TIME */
            gettime( &ts );
            currtime=(long)ts.ti_hund;
            if ( endtime-currtime > 50 ) currtime+=100;
/*
            CHECK WHETHER A NEW CHARACTER HAS APPEARED */
            status=GetStatus() & 0x0100;
         }
/*
         IF STATUS IS ZERO, HOLDING LOOP TIMED OUT, BRK FOR DAMAGE CONTROL*/
         if(status==0) break;
```

```
/*
         COPY THE NEW CHARACTER INTO DATA STORAGE */
         *(dptr[nsamp]+k)=( unsigned char )( Receive() & 0x00ff );
      }
/*
      RETURN HERE IF ALL 48 CHARACTERS WERE READ SUCCESSFULLY */
      if(status!=0) return;
/*
      IF READ WAS NOT SUCCESSFUL, STOP XMSN, CLEAR REGISTER, RESTART XMSN */
      Transmit('D');
      delay(100);
      status=GetStatus() & 0x0100;
      while ( status ){
         Receive();
         status=GetStatus() & 0x0100;
      }
      Transmit('E');
   }
/*
   MAX NUMBER OF READ ATTEMPTS EXCEEDED, INSERT DUMMY VALUES */
   if(nsamp > 0){
/*
      IF NOT FIRST DATA RECORD, COPY ALL PREVIOUS VALUES */
      for ( k=0; k<48; k++) *(dptr[nsamp]+k)=*(dptr[nsamp-1]+k);
   }
   else{
/*
      IF FIRST DATA RECORD, CLEAR ALL DATA LOCATIONS IN CURRENT SAMPLE */
      for ( k=0; k<48; k++) *(dptr[nsamp]+k)=0x00;
   }
/*
   CHANGE BIN NUMBERS TO A LARGE POSITIVE VALUE (248) */
   for ( k=0; k<16; k++ ) *(dptr[nsamp]+k*3) = 0xf8;
/*
   IF 0.2 SECOND SAMPLING (TSAMP=0), ADD ANOTHER SCAN TO FILL OUT TIME */
   if(tsamp != 0) return;
   if(nsamp >= 5999) return;
   nsamp++;
   dptr[nsamp] = malloc(48);
   for ( k=0; k<48; k++) *(dptr[nsamp]+k)=*(dptr[nsamp-1]+k);
   return;
}

void FakeRecord(void){
  dptr[nsamp] = malloc(48);
  for ( k=0; k<4; k++ ){
/*
    ASSIGN BIN VALUES */
    *(dptr[nsamp]+k*12+ 0) = (unsigned char)((nsamp+k*4+1) & 0x00ff);
    *(dptr[nsamp]+k*12+ 3) = (unsigned char)((nsamp+k*4+2) & 0x00ff);
    *(dptr[nsamp]+k*12+ 6) = (unsigned char)((nsamp+k*4+3) & 0x00ff);
    *(dptr[nsamp]+k*12+ 9) = (unsigned char)((nsamp+k*4+4) & 0x00ff);
/*
    *(dptr[nsamp]+k*12+ 0) = 0xf8;
    *(dptr[nsamp]+k*12+ 3) = 0xf8;
    *(dptr[nsamp]+k*12+ 6) = 0xf8;
```

```
    *(dptr[nsamp]+k*12+ 9) = 0xf8; */

/*
    ASSIGN DEVIATION VALUES */
    *(dptr[nsamp]+k*12+ 1) = (unsigned char)((nsamp+k*4+1) & 0x00ff);
    *(dptr[nsamp]+k*12+ 2) = (unsigned char)(( nsub+k*4+1) & 0x00ff);
    *(dptr[nsamp]+k*12+ 4) = (unsigned char)((nsamp+k*4+2) & 0x00ff);
    *(dptr[nsamp]+k*12+ 5) = (unsigned char)(( nsub+k*4+2) & 0x00ff);
    *(dptr[nsamp]+k*12+ 7) = (unsigned char)((nsamp+k*4+3) & 0x00ff);
    *(dptr[nsamp]+k*12+ 8) = (unsigned char)(( nsub+k*4+3) & 0x00ff);
    *(dptr[nsamp]+k*12+10) = (unsigned char)((nsamp+k*4+4) & 0x00ff);
    *(dptr[nsamp]+k*12+11) = (unsigned char)(( nsub+k*4+4) & 0x00ff);
  }
  delay(200);
  return;
}

void AvgOpen(void){
unsigned int inp;
float ana;
float vtemp;
/*
   PUT DATA IN BUFFER POSITION NSAMP */
   nsub=0;
   GetData();
/*
   COPY DATA INTO HOLDING BUFFER FOR COMPARING BINS LATER */
   for ( k=0; k<48; k++ ) abuf[k]=*( dptr[nsamp]+k );
/*
   INITIALIZE THE NUMBER OF SUB-SAMPLES (CHECK VALIDITY OF SAMPLE) */
   for ( k=0; k<16; k++ ){
     if( *(dptr[nsamp]+k*3) != 0xf8) nsub=1;
   }
/*
   COPY DEVIATION VALS INTO DSUM (SUMMATION BUFFER) (INDEX ON AXIS) */
   if(nsub == 1){
      for (k=0; k<3; k++){
         inp=( *(dptr[nsamp]+ 1+k*3)<<8 ) + *(dptr[nsamp]+ 2+k*3);
         ana=(float)( inp-32768 );
         dsum[k]=(double)(ana);
         inp=( *(dptr[nsamp]+13+k*3)<<8 ) + *(dptr[nsamp]+14+k*3);
         ana=(float)( inp-32768 );
         dsum[4+k]=(double)(ana);
         inp=( *(dptr[nsamp]+25+k*3)<<8 ) + *(dptr[nsamp]+26+k*3);
         ana=(float)( inp-32768 );
         dsum[8+k]=(double)(ana);
         inp=( *(dptr[nsamp]+37+k*3)<<8 ) + *(dptr[nsamp]+38+k*3);
         ana=(float)( inp-32768 );
         dsum[12+k]=(double)(ana);
      }
/*
      COPY TEMPERATURE VALUES INTO DSUM (INDEX ON MAG#) */
      for ( k=0; k<4; k++){
         inp=( *(dptr[nsamp]+10+k*12)<<8 ) + *(dptr[nsamp]+11+k*12);
         vtemp=(float)( inp-32768 );
         dsum[3+4*k]=(double)(vtemp);
```

```
      }
   }
/*
   FREE THE POINTER AT NSAMP */
   free( dptr[nsamp] );
   return;
}

void AvgSum(void){
unsigned int inp;
unsigned int jmatch;
float ana;
float vtemp;
int jadd;
/*
   PUT DATA IN BUFFER POSITION NSAMP */
   GetData();
/*
   CHECK BIN NUMBERS IN NEW SUB-SAMPLE AGAINST FIRST SUB-SAMPLE */
   jmatch=1;
   for ( k=0; k<16; k++ ){
      if ( abuf[3*k] != *( dptr[nsamp]+3*k ) ) jmatch=0;
   }
/*
   DETERMINE WHETHER TO INITIALIZE DSUM AND RE-INIT ABUF */
   if(jmatch == 0 && nsub == 0){
      jadd=1;
/*
      COPY DATA INTO HOLDING BUFFER FOR COMPARING BINS LATER */
      for ( k=0; k<48; k++ ) abuf[k]=*( dptr[nsamp]+k );
/*
      INITIALIZE DSUM TO ZEROS */
      for ( k=0; k<16; k++ ) dsum[k]=0;
   }
   if(jmatch == 0 && nsub != 0) jadd=0;
   if(jmatch == 1 && nsub == 0) jadd=0;
   if(jmatch == 1 && nsub != 0) jadd=1;
/*
   ADD THE DEVIATION VALUES INTO DSUM (INDEX ON AXIS) */
   if ( jadd == 1 ){
      for (k=0; k<3; k++){
         inp=( *(dptr[nsamp]+ 1+k*3)<<8 ) + *(dptr[nsamp]+ 2+k*3);
         ana=(float)( inp-32768 );
         dsum[k]=dsum[k]+(double)(ana);
         inp=( *(dptr[nsamp]+13+k*3)<<8 ) + *(dptr[nsamp]+14+k*3);
         ana=(float)( inp-32768 );
         dsum[4+k]=dsum[4+k]+(double)(ana);
         inp=( *(dptr[nsamp]+25+k*3)<<8 ) + *(dptr[nsamp]+26+k*3);
         ana=(float)( inp-32768 );
         dsum[8+k]=dsum[8+k]+(double)(ana);
         inp=( *(dptr[nsamp]+37+k*3)<<8 ) + *(dptr[nsamp]+38+k*3);
         ana=(float)( inp-32768 );
         dsum[12+k]=dsum[12+k]+(double)(ana);
      }
/*
      COPY TEMPERATURE VALUES INTO DSUM (INDEX ON MAG#) */
```

```
      for ( k=0; k<4; k++){
         inp=( *(dptr[nsamp]+10+k*12)<<8 ) + *(dptr[nsamp]+11+k*12);
         vtemp=(float)( inp-32768 );
         dsum[3+4*k]=dsum[3+4*k]+(double)(vtemp);
      }
/*
      INCREMENT THE NUMBER OF SUB-SAMPLES WITHIN DSUM */
      nsub=nsub+1;
   }
/*
   FREE THE POINTER AT NSAMP */
   free( dptr[nsamp] );
   return;
   }

void AvgClose(void){
unsigned int inp;
float ana;
float vtemp;
/*
   ALLOCATE SPACE AT THE CURRENT SAMPLE POINTER */
   dptr[nsamp] = malloc(48);
/*
   FIND WHETHER GOOD DATA WAS RECEIVED */
   if(nsub == 0){
/*
      COPY DUMMY DATA FROM HOLDING BUFFER BACK INTO DATA ARRAY */
      for ( k=0; k<48; k++ ) *( dptr[nsamp]+k )=abuf[k];
      return;
   }
/*
   COPY THE BIN NUMBERS FROM FIRST SUB-SAMPLE INTO SAMPLE BUFFER */
   for ( k=0; k<16; k++ ){
      *( dptr[nsamp]+3*k )=abuf[3*k];
   }

/*
   FIND AVERAGE AND PUT BACK INTO SAMPLE ARRAY, DPTR (INDEX ON AXIS) */
   for (k=0; k<3; k++){
      dsum[k]=dsum[k]/((double)(nsub));
      ana=(float)(dsum[k]);
      inp=(unsigned int)(ana+32768.);
      *(dptr[nsamp]+ 1+k*3)=(unsigned char)(inp>>8);
      *(dptr[nsamp]+ 2+k*3)=(unsigned char)(inp & 0x00ff);

      dsum[4+k]=dsum[4+k]/((double)(nsub));
      ana=(float)(dsum[4+k]);
      inp=(unsigned int)(ana+32768.);
      *(dptr[nsamp]+ 13+k*3)=(unsigned char)(inp>>8);
      *(dptr[nsamp]+ 14+k*3)=(unsigned char)(inp & 0x00ff);

      dsum[8+k]=dsum[8+k]/((double)(nsub));
      ana=(float)(dsum[8+k]);
      inp=(unsigned int)(ana+32768.);
      *(dptr[nsamp]+ 25+k*3)=(unsigned char)(inp>>8);
      *(dptr[nsamp]+ 26+k*3)=(unsigned char)(inp & 0x00ff);
```

```
      dsum[12+k]=dsum[12+k]/((double)(nsub));
      ana=(float)(dsum[12+k]);
      inp=(unsigned int)(ana+32768.);
      *(dptr[nsamp]+ 37+k*3)=(unsigned char)(inp>>8);
      *(dptr[nsamp]+ 38+k*3)=(unsigned char)(inp & 0x00ff);
   }
/*
   FIND AVG TEMPs & PUT BACK INTO SAMPLE ARRAY, DPTR (INDEX ON MAG#) */
   for ( k=0; k<4; k++){
      dsum[3+4*k]=dsum[3+4*k]/((double)(nsub));
      vtemp=(float)(dsum[3+4*k]);
      inp=(unsigned int)(vtemp+32768.);
      *(dptr[nsamp]+ 10+k*12)=(unsigned char)(inp>>8);
      *(dptr[nsamp]+ 11+k*12)=(unsigned char)(inp & 0x00ff);
   }
   return;
}
```

APPENDIX E. SAMPLE OF PRIMARY DATA FILE

Following are example records are from a primary data file (dec12m8m.dat) produced by the KMGR program. In order to present the records here, they have been modified as follows:

1) A circumflex (^) has been put in place of the newline character which is at the beginning of each data record (but not the header record),
2) A dollar sign ($) has been appended at the end of each record, and
3) The record has been wrapped to fit on the page.

```
KMGR data 12 16 10:43:13120 MONITOR IN LAVA TUBE, MILE 8
 MARKER, HVO, HI                              $
^ 0000  396FA5FFCA8C1E83A702A542F549AB00A8BFC17FD905A5D1
E38098A88A291A7F9F03AA8BDC86B25891F019A81201A985$
^ 0001  396FBCFFCA8A1E83A802A547F549B100A8C1C17FC405A5D5
E3808CA88A1C1A7FAC03AA88DC86A25891FE19A81B01A987$
^ 0002  396FD4FFCA841E83AC02A54BF549B400A8C6C17FAB05A5D9
E38081A88A0B1A7FB903AA7FDC869158921019A82101A98E$
^ 0003  396FEBFFCA811E83AE02A552F549B700A8C9C17F9505A5DF
E38075A889F91A7FC503AA88DC868058921D19A829019BE9$
.           .           .           .           .
.           .           .           .           .
.           .           .           .           .
^ 2939  396CA9FFCBDC1E80AD02A825F54BA100A721C183C905A87D
E38026A88E571A7DF703ACF7DC8836588D9019A8E201AC66$
^ 2940  396C9BFFCBD61E80A502A82FF54BA100A724C183D805A886
E3802DA88E651A7DF403ACFFDC883B588D8119A8D901A0CD$
^ 2941  396C94FFCBD11E80A202A836F54B9E00A728C183E305A88C
E38034A88E6C1A7DF203AD09DC883C588D7719A8D1019BA6$
```

Each byte in the file is first to be interpreted standard ASCII (ASC) (as in the above example). Subsequently, the ASCII characters should remain ASCII or be interpreted again as either integer (INT) or hexadecimal (HEX). The basic file structure contains one 88-character (88-byte) header record followed by up to 6000 data records, each having 104 characters including the newline. The first character of each data record is a newline character but the header record does not have a one.

The header record is formatted and interpreted as follows:

```
KMGS data 10 21 14:03:29120 monitor in lava tube, mile 8
 marker, hvo, hi                              $

PPPP data NN DD HH:MM:SSRRR CCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCC$
```

Where (interpretation in parenthesis):

P - (ASC) Program name, "KMGS" or "KMGR"
  - (ASC) Literal blank " "
data - (ASC) Literal word "data"
N - (INT) moNth when the data were SAVED TO DISK

```
D - (INT) Day of the month when the data were SAVED TO DISK
H - (INT) Hour of the day when data SAMPLING BEGAN
: - (ASC) Literal colon ":"
M - (INT) Minute of the hour when data SAMPLING BEGAN
S - (INT) Second of the minute when data SAMPLING BEGAN
R - (INT) sampling Rate in seconds (000 => 0.2-second rate)
C - (ASC) Comment added at the beginning of sampling.
```

The data records are formatted as follows. The newline is interpreted ASCII; the sample offset is interpreted integer; and the rest of the record is interpreted hexadecimal.

```
A 0003  38C7E10132571EBE7300AB85F4907C0087B8C227CA05ABFE
E37B93A883CF1A604D03AEA8DD5FF2589B1B1A74E901AF74$

A IIII  xxXXXXyyYYYYzzZZZZssTTTTxxXXXXyyYYYYzzZZZZssTTTT
xxXXXXyyYYYYzzZZZZssTTTTxxXXXXyyYYYYzzZZZZssTTTT$
```

Where (interpretation in parenthesis):

```
A - (ASC) Newline character (value = 10)
  - (ASC) Literal blank " "
I - (INT) Sample offset (sample number minus 1)
x - (HEX) Bin number of the x axis
X - (HEX) Deviation voltage of the x axis
y - (HEX) Bin number of the y axis
Y - (HEX) Deviation voltage of the Y axis
z - (HEX) Bin number of the z axis
Z - (HEX) Deviation voltage of the Z axis
```

Each group of xxXXXXyyYYYYzzZZZZssTTTT is 24 characters long and corresponds sequentially with each of the 4 magnetometers.

The bin number of each axis is a 9-bit binary two's complement number (-256 to +255) with the first 8 bits for each axis in xx, yy, or zz; the ninth bit is in ss where the bit corresponds to the axis (the x-axis sign is in ss bit offset 0).

The deviation voltage of each axis is obtained by the formula (X-32768)*0.0002 where X is the value in XXXX, YYYY, or ZZZZ. The temperature is (TTTT-32768)*0.002.

APPENDIX F. DATA FILES LISTING

In this appendix, information is given about the data files produced during the 10 months of monitoring. Table F-1 shows file names, beginning and ending dates and times, and the supporting data used to arrive at average sampling rates.

In every data file, the sampling rate was set exactly to 120 seconds per sample according to the clock on the data acquisition computer (PC). However, the PC clock was effected slightly by interrupts produced by the data acquisition programs, KMGS9 and KMGR. To quantify the interrupts' effect, the PC time and true time were recorded shortly after each data file was completed; then the PC clock was reset to the true time before beginning a new file.

From these data, a true sample rate was derived for each file. In every instance (except one), the true sample rates vary from a weighted average sample rate by an amount which produces variations in file durations no larger than ±1 minute. (The exception produces less than 2 minutes of difference).

Because the clock rates among the files are consistent to within 1 sample period, it was concluded that a weighted average sample rate should be used for each of the two programs making each rate applicable to any data file produced by its corresponding program. The weighted average sample rate for the KMGS9 program (jun12 - nov14) is 119.9830 seconds; for the KMGR program (nov15 - mar31), it is 120.8422 seconds. These average rates were used for calculating the ending dates and times of the data files given the beginning dates and times and the numbers of samples.

TABLE F-1: MONITORING-DATA FILES, TIMES, AND RATES

FILE NAME/NBR - The DOS disk name of the original data file. The next line contains a file sequence number for digital reference.

BEG/END yymmdd.hhmmss - The beginning date and time with the ending date and time on the next line expressed as year, month, day, hour, minute, and second Hawaii Standard Time (-10 hours from UTC). Note that the ending time is calculated from the WEIGHTED AVERAGE SAMPLE RATE given above, not the rate appearing in the rate column.

BEG/END doy94 - Beginning and ending date and time as in the previous column except expressed as the decimal day of the year 1994. For example, noon on January 1, 1994 would be 1.50000; noon on January 1, 1995 would be 366.50000. In other words, time in decimal days is reckoned from a zero datum of December 31, 1993 at midnight (1 day before the new year begins).

NSAMP - The number of data samples in the data file.

RATE sec - The sample rate calculated specifically for each file using the PC-clock time adjustments in the next column. The rates in this column together with the NSAMP's from the previous column were used to derive the two weighted average rates.

PCT/TRU hhmmss - The PC time in hours, minutes, and seconds given by the PC clock shortly after the data collection was completed. The next line contains the true time in hours, minutes, and seconds from a wrist watch set by Universal Time. Both PC time and true time were typically recorded in the notes. However, if the true time is showing 000000, times were not recorded, in which case the PC time has been estimated.

PCTERR sec - The difference in seconds between the PC time and the true time (PCT minus TRU).

FILE NAME/NBR	BEG/END yymmdd.hhmmss	BEG/END doy94	NSAMP	RATE sec	PCT/TRU hhmmss	PCTERR sec
jun12m69.dat	940612.065439	163.28795	867	119.9827	000015	15
1	940613.114824	164.49194			000000	
jun13m8m.dat	940613.133823	164.56832	2760	119.9830	000047	47
2	940617.093736	168.40111			000000	
jun17m8m.dat	940617.100308	168.41884	2267	119.9828	000039	39
3	940620.133629	171.56700			000000	

jun20m8m.dat	940620.140304	171.58546	2140	119.9832	000036	36
4	940623.132228	174.55727			000000	
jun28m8a.dat	940628.102246	179.43248	140	119.9857	000002	2
5	940628.150244	179.62690			000000	
jun28m8b.dat	940628.152129	179.63992	610	119.9836	000010	10
6	940629.114119	180.48703			000000	
jun29m8m.dat	940629.114431	180.48925	660	119.9667	101607	22
7	940630.094420	181.40579			101545	
jun30m8a.dat	940630.104159	181.44582	104	119.9808	000002	2
8	940630.140957	181.59024			000000	
jul1m8m.dat	940701.100303	182.41878	2887	119.9809	102410	55
9	940705.101614	186.42794			102315	
jul5m8a.dat	940705.102519	186.43425	82	119.9878	000001	1
10	940705.130918	186.54813			000000	
jul5m8b.dat	940705.131245	186.55052	2153	119.9828	000037	37
11	940708.125808	189.54037			000000	
jul21m8m.dat	940721.093604	202.40005	2996	120.0013	132926	-4
12	940725.132713	206.56057			132930	
jul25m8m.dat	940725.133643	206.56716	2960	120.0017	161835	-5
13	940729.161553	210.67770			161840	
aug8m8m.dat	940808.104517	220.44811	677	119.9823	092812	12
14	940809.091905	221.38825			092800	
aug9m8m.dat	940809.092950	221.39572	778	119.9820	112714	14
15	940810.112537	222.47612			112700	
aug10m8m.dat	940810.114628	222.49060	3612	119.9817	121346	66
16	940815.120927	227.50656			121240	
aug15m8m.dat	940815.121512	227.51056	5094	119.9837	141023	83
17	940822.140145	234.58455			140900	
aug22m8m.dat	940822.141049	234.59084	5042	119.9837	142122	82
18	940829.141323	241.59263			142000	
sep6m8m.dat	940906.104300	249.44653	4350	119.9713	114405	125
19	940912.114146	255.48734			114200	
sep12m8m.dat	940912.114507	255.48966	5736	119.9829	110153	98
20	940920.105529	263.45520			110015	
sep20m8m.dat	940920.110152	263.45963	4346	119.9777	115637	97
21	940926.115238	269.49488			115500	

oct03m8m.dat	941003.105759	276.45693	5753	119.9797	104857	117
22	941011.104221	284.44608			104700	
oct11m8m.dat	941011.104816	284.45019	4416	119.9830	000115	75
23	941017.135901	290.58265			000000	
oct17m8m.dat	941017.140329	290.58575	2741	119.9628	103602	102
24	941021.092442	294.39215			103420	
oct21m8m.dat	941021.103529	294.44131	2168	119.9723	105430	60
25	941024.105052	297.45199			105330	
oct24m8m.dat	941024.105508	297.45495	5020	119.9807	142037	97
26	941031.101343	304.42619			141900	
nov8m8m.dat	941108.094931	312.40939	4355	120.0039	134053	-17
27	941114.105817	318.45714			134110	
nov14m8m.dat	941114.134232	318.57120	620	119.9823	000011	11
28	941115.102221	319.43219			000000	
nov15m8m.dat	941115.115518	319.49674	114	120.8333	000000	-95
29	941115.154454	319.65618			000135	
nov22m8m.dat	941122.095619	326.41411	5041	120.8439	100216	-4254
30	941129.110905	333.46464			111310	
nov29m8m.dat	941129.111439	333.46851	4280	120.8404	095838	-3597
31	941205.105444	339.45468			105835	
	(TRU, 105835 is 1 hour earlier in the field notes)					
dec05m8m.dat	941205.110626	339.46280	4991	120.8431	093052	-4208
32	941212.103829	346.44339			104100	
	(PC clock had been set 1 hour early for this file)					
dec12m8m.dat	941212.104313	346.44668	2942	120.8423	124852	-2478
33	941216.132831	350.56147			133010	
dec16m8m.dat	941216.135423	350.57943	5999	120.8341	092856	-5004
34	941224.231635	358.96985			105220	
dec27m8m.dat	941227.105739	361.45670	5109	120.8415	131631	-4299
35	950103.142722	368.60234			142810	
jan03m8m.dat	950103.143232	368.60593	4192	120.8407	102016	-3524
36	950109.111523	374.46902			111900	
jan17m8m.dat	950117.132758	382.56109	4297	120.8546	124418	-3672
37	950123.134217	388.57103			134530	
jan31m8m.dat	950131.135609	396.58066	4208	120.8417	101558	-3542
38	950206.111113	402.46612			111500	

```
feb06m8m.dat 950206.111631 402.46980  5011 120.8408 101917  -4213
     39      950213.112851 409.47837                112930
             (TRU misprinted in notes, 111930 probably 112930)

feb13m8m.dat 950213.113305 409.48131  3346 120.8435 101537  -4823
     40      950218.035203 414.16115                113600
             (samples 3347 - 5718 lost, hard disk was full)

feb21m8m.dat 950221.145342 417.62063  4171 120.8437 100009  -3519
     41      950227.105415 423.45434                105848

feb27m8m.dat 950227.110044 423.45884  5013 120.8394 100852  -4208
     42      950306.111706 430.47021                111900

mar06m8m.dat 950306.112434 430.47539  5083 120.8495 125502  -4318
     43      950313.140155 437.58466                140700

mar13m8m.dat 950313.140814 437.58905  2718 120.8433 093603  -2292
     44      950317.092223 441.39054                101415

mar17m8m.dat 950317.101544 441.42759  2243 120.8391 130231  -1882
     45      950320.133313 444.56473                133353

mar20m8m.dat 950320.133849 444.56862  5024 120.8408 130836  -4224
     46      950327.141720 451.59537                141900

mar27m8m.dat 950327.142341 451.59978  2730 120.8425 093002  -2300
     47      950331.100200 455.41806                100822

mar31m8m.dat 950331.101007 455.42369  2161 120.8348 101150  -1804
     48      950403.104227 458.44615                104154
```

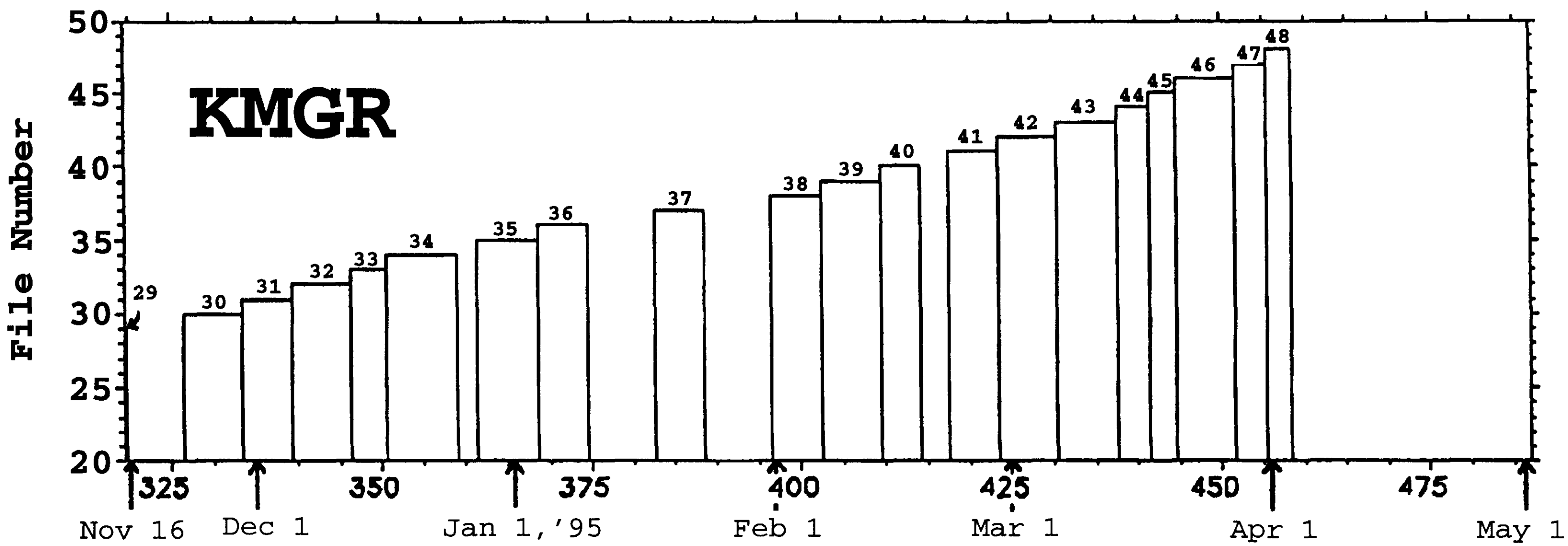
APPENDIX G. DATA-COVERAGE RECORD

In this appendix, a description of the monitoring-data coverage is given in both figure and table formats. The table includes explanations for periods of data loss.

Figure G-1 contains two bar graphs showing the time periods of data collection for the data files given in appendix F. The lower graph shows files produced by the KMGS9 program, the upper, those by KMGR. "Missing" bars indicate significant periods of data loss. The horizontal axis is time, marked as day of the year 1994 with a pointer at the beginning of each month. The vertical axis is file number. For clarity, the file numbers are also given explicitly at the tops of the bars. Both, the unit of time and the file number are as defined in appendix F.

Table G-1 shows the duration of each gap between data files. If the gap is of sufficient duration or contains significant events, an explanation will also be provided. When an explanation is not provided for a gap, it is implied that only a routine procedure for changing files occurred.

Figure G-1. Bar graphs showing the file numbers and time periods of data collection.



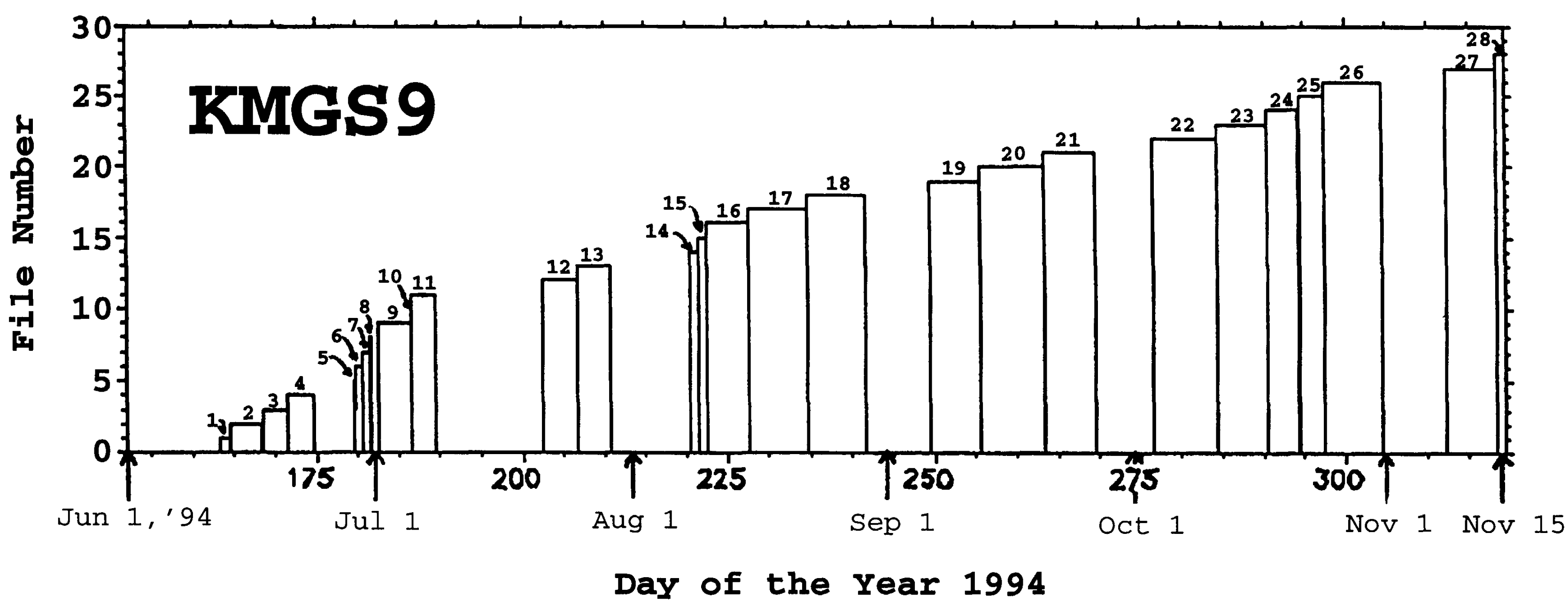


TABLE G-1: MONITORING-DATA COVERAGE IN LIST FORM

GAP_ID - The identification of the gap given as the bounding data-file numbers separated by a comma.

BEG/END date, hh:mm - The beginning date and time of the gap with the ending date and time on the next line. The seconds have been truncated and the form of the date has been made for easy reference to the field notes.

BEG/END doy94 - Beginning date and time of the gap as in the previous column except expressed as the decimal day of the year 1994. The form of this date has been made for easy reference to the data coverage bar graph and to appendix F.

DURATION days - The gap duration between the bounding data files, given in decimal days. (Note that an hour is about 0.04 days.)

GAP_ID	BEG/END date, hh:mm	BEG/END doy94	DURATION days
--, 1	--- --, --:--	---.-----	-.-----
	Jun 12, 6:54	163.28795	
	Beginning of this monitoring experiment.		
1, 2	Jun 13, 11:48	164.49194	0.07638
	Jun 13, 13:38	164.56832	
	A rotation calibration was performed and final instructions were given to the HVO staff.		
2, 3	Jun 17, 9:37	168.40111	0.01773
	Jun 17 10:03	168.41884	
3, 4	Jun 20, 13:36	171.56700	0.01846
	Jun 20 14:03	171.58546	
4, 5	Jun 23, 13:22	174.55727	4.87521
	Jun 28, 10:22	179.43248	
	An entire data set was lost due to stoppage of data output from Morris coupled with an inability of the KMGS9 program to handle that type of error. Stoppage was probably caused by the power supply being near failure. The data output was restarted by cycling the power to Morris.		
5, 6	Jun 28, 15:02	179.62690	0.01302
	Jun 28 15:21	179.63992	
	The control link for the Morris temperature had been lost, probably attributable to the power supply being near failure. The data set was not lost but data collection had to be stopped briefly in order to restore the link.		

6, 7	Jun 29, 11:41	180.48703	0.00222
	Jun 29 11:44	180.48925	
7, 8	Jun 30, 9:44	181.40579	0.04003
	Jun 30 10:41	181.44582	

The control link for the Morris temperature had been lost. It was restored and a new data file started.

8, 9	Jun 30, 14:09	181.59024	0.82854
	Jul 1, 10:03	182.41878	

An entire data set was lost due to stoppage of data output from Morris coupled with an inability of the KMGS9 program to handle that type of error. Stoppage was probably caused by the power supply being near failure. The data output was restarted by cycling the power to Morris.

9,10	Jul 5, 10:16	186.42794	0.00631
	Jul 5 10:25	186.43425	
10,11	Jul 5, 13:09	186.54813	0.00239
	Jul 5 13:12	186.55052	
11,12	Jul 8, 12:58	189.54037	12.85968
	Jul 21, 9:36	202.40005	

The failed power supply was sent back to Denver for redesign. The new power supply was received at HVO on Jul 20.

12,13	Jul 25, 13:27	206.56057	0.00659
	Jul 25 13:36	206.56716	
13,14	Jul 29, 16:15	210.67770	9.77041
	Aug 8, 10:45	220.44811	

An entire data set was lost due to an end-of-the-month bug in KMGS9.

14,15	Aug 9, 9:19	221.38825	0.00747
	Aug 9 9:29	221.39572	
15,16	Aug 10, 11:25	222.47612	0.01448
	Aug 11:46	222.49060	
16,17	Aug 15, 12:09	227.50656	0.00400
	Aug 15 12:15	227.51056	
17,18	Aug 22, 14:01	234.58455	0.00629
	Aug 22 14:10	234.59084	

18,19	Aug 29, 14:13	241.59263	7.85390
	Sep 6, 10:43	249.44653	
	An entire data set was lost due to an end-of-the-month bug in KMGS9.		
19,20	Sep 12, 11:41	255.48734	0.00232
	Sep 12 11:45	255.48966	
20,21	Sep 20, 10:55	263.45520	0.00443
	Sep 20 11:01	263.45963	
21,22	Sep 26, 11:52	269.49488	6.96205
	Oct 3, 10:57	276.45693	
	An entire data set was lost due to an end-of-the-month bug in KMGS9.		
22,23	Oct 11, 10:42	284.44608	0.00411
	Oct 11 10:48	284.45019	
23,24	Oct 17, 13:59	290.58265	0.00310
	Oct 17 14:03	290.58575	
24,25	Oct 21, 9:24	294.39215	0.04916
	Oct 21 10:35	294.44131	
	A rotation calibration was performed.		
25,26	Oct 24, 10:50	297.45199	0.00296
	Oct 24 10:55	297.45495	
26,27	Oct 31, 10:13	304.42619	7.98320
	Nov 8, 9:49	312.40939	
	An entire data set was lost due to an end-of-the-month bug in KMGS9.		
27,28	Nov 14, 10:58	318.45714	0.11406
	Nov 14 13:42	318.57120	
	A battery was replaced.		
28,29	Nov 15, 10:22	319.43219	0.06455
	Nov 15 11:55	319.49674	
	The KMGR program was installed in place of KMGS9.		
29,30	Nov 15, 15:44	319.65618	6.75793
	Nov 22, 9:56	326.41411	
	Tests and demonstrations preempted the TMGS from Nov 15 - 17. A rotation calibration was performed on Nov 17. The remaining data-set from Nov 18 - 22 was lost because the data acquisition computer failed due to a dead internal battery.		
30,31	Nov 29, 11:09	333.46464	0.00387
	Nov 29 11:14	333.46851	
31,32	Dec 5, 10:54	339.45468	0.00812
	Dec 5 11:06	339.46280	

32,33	Dec 12,	10:38	346.44339	0.00329
	Dec 12	10:43	346.44668	
33,34	Dec 16,	13:28	350.56147	0.01796
	Dec 16	13:54	350.57943	
34,35	Dec 24,	23:16	358.96985	2.48685
	Dec 27,	10:57	361.45670	

The memory of the data acquisition computer became full on Christmas eve and it ceased to collect data until it could be serviced after the Holiday.

35,36	Jan 3,	14:27	368.60234	0.00359
	Jan 3	14:32	368.60593	
36,37	Jan 9,	11:15	374.46902	8.09207
	Jan 17,	13:27	382.56109	

An entire data set was lost because the computer could not be accessed. The probable cause was a low battery voltage from too little sunshine on the solar panel.

37,38	Jan 23,	13:42	388.57103	8.00963
	Jan 31,	13:56	396.58066	

An entire data set was lost because the computer could not be accessed. The probable cause was a low battery voltage from too little sunshine on the solar panel.

38,39	Feb 6,	11:11	402.46612	0.00368
	Feb 6	11:16	402.46980	
39,40	Feb 13,	11:28	409.47837	0.00294
	Feb 13	11:33	409.48131	
40,41	Feb 18,	3:52	414.16115	3.45948
	Feb 21,	14:53	417.62063	

Part of the data set was lost because the hard disk filled up before the final 2372 samples could be transferred from memory.

41,42	Feb 27,	10:54	423.45434	0.00450
	Feb 27	11:00	423.45884	
42,43	Mar 6,	11:17	430.47021	0.00518
	Mar 6	11:24	430.47539	
43,44	Mar 13,	14:01	437.58466	0.00439
	Mar 13	14:08	437.58905	

44,45	Mar 17,	9:22	441.39054	0.03705
	Mar 17	10:15	441.42759	

A rotation calibration was performed and TESSA was left in a new attitude with MAG 4 on top and MAG 3 to the north.

45,46	Mar 20,	13:33	444.56473	0.00389
	Mar 20	13:38	444.56862	
46,47	Mar 27,	14:17	451.59537	0.00441
	Mar 27	14:23	451.59978	
47,48	Mar 31,	10:02	455.41806	0.00563
	Mar 31	10:10	455.42369	

The "lift test" was performed.

48,--	Apr 3,	10:42	458.44615	-.-----
	--- --,	--:--	---.-----	

End of this monitoring experiment. The site was dismantled.

APPENDIX H. MORRIS TEMPERATURE RECORDS FROM FIELD NOTES

In this appendix, figure H-1 is a graph showing the temperatures inside Morris superimposed on bar graphs of the data files. The temperatures were recorded by hand from an independent temperature monitoring unit. Morris temperature data were only recorded at the beginning and ending of each data file; the graph shows straight line interpolation between the data points. Therefore, the data cannot be used quantitatively for removing Morris-temperature correlated waveforms; but the graph can be used qualitatively to help analyze overall trends in the gradient data and to help determine whether artifacts of Morris-temperature fluctuations may be present.

The target Morris-temperature was 35±0.15°C which was maintained during the summer months. However, during the winter months fluctuations approached ±0.7°C. The resulting rms gradient error is shown in table 1D.

Table H-1 (following figure H-1) is simply a listing of the dates, times (in hours and minutes), and Morris-temperature values extracted from the field notes and used to produce the figure graph. An occasional battery voltage to the right of the temperature column refers to the 9-V battery inside the independent temperature monitor. (Extensive testing indicated that the temperature monitor was accurate to within ±0.05°C over all battery voltages above 7.5 V). An occasional at-sign (@) to the right of the temperature column indicates that the temperature entry is synthetic data added to improve readability in the figure graph.

Figure H-1. Temperatures inside Morris from field notes.

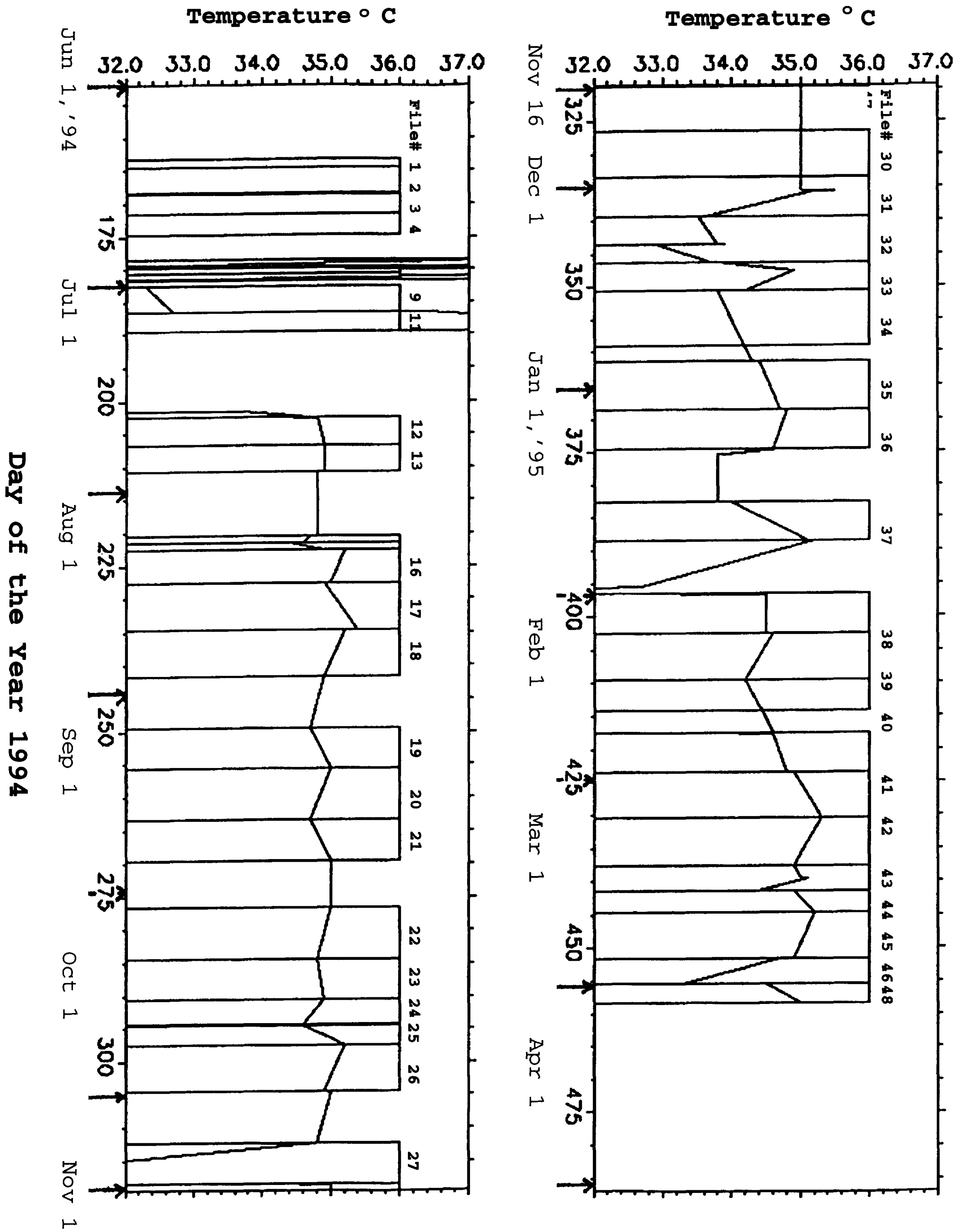


TABLE H-1: MORRIS TEMPERATURE DATA

DATE/TIME	TEMP°C	MONITOR VOLTAGE
June 27, 1994		
1306	41.7	battery: 9.30 V
1330	37.8	
June 28, 1994		
0957	32.8	
1013	31.3	
1014	31.5	
1019	31.7	
1020	31.8	
1022	32.1	
1501	42.1	
1515	34.1	
1516	34.4	
1518	34.7	
1520	34.9	
1524	35.1	
1526	35.2	
1528	35.3	
1530	35.4	
1533	35.5	
1536	35.6	
1537	31.1	
1539	29.7	
1540	33.0	
1541	33.3	
1542	33.4	
June 29, 1994		
1136	40.9	
1144	41.2	battery: 9.10 V
1154	41.3	
1213	41.4	
June 30, 1994		
0935	33.0	
1015	30.2	
1019	30.6	
1023	31.0	
1031	31.3	
1037	31.6	
1042	31.8	
1048	31.9	
1052	32.1	
1100	32.3	
1106	32.5	
1404	37.5	
1405	30.0	
1446	30.3	
1453	30.7	
1501	30.9	
1508	31.4	

July 1, 1994		
0920	31.7	
1006	32.0	
1023	32.3	
July 5, 1994		
1011	32.7	
1026	32.9	
1307	36.3	
1312	36.4	
July 8, 1994		
1255	41.8	
1305	41.8	
1400	25.0	@ synthetic data
July 20, 1994		
1055	25.0	@ synthetic data
1111	27.3	
1113	31.0	
1117	31.9	
1122	33.7	
July 21, 1994		
0902	34.7	
0915	34.7	
0921	33.6	battery: 9.17 V
0933	31.1	
0937	34.2	
1314	34.7	
1325	34.8	
July 25, 1994		
1323	34.9	
1336	34.9	
July 29, 1994		
1612	34.9	
1620	34.9	
1625	34.8	
Aug 8, 1994		
1038	34.8	
1045	34.8	
1054	34.7	
Aug 9, 1994		
0914	34.6	
0917	34.6	
0920	34.5	
0927	34.2	
0928	35.2	
0929	35.1	
0940	34.5	
0949	34.4	
Aug 10, 1994		
1122	34.9	
1128	35.0	
1144	35.5	
1146	35.4	
1149	35.2	battery: 8.69 V

Aug 15, 1994		
1205	35.0	
1216	34.9	
Aug 22, 1994		
1350	35.4	
1413	35.2	battery: 8.67 V
Aug 29, 1994		
1410	34.9	
1422	34.9	
Sep 6 1994		
1037	34.7	
1049	34.7	
Sep 12, 1994		
1136	35.0	battery: 8.72 V
1145	35.0	
Sep 20, 1994		
1052	34.7	battery: 8.71 V
1107	34.7	
Sep 26, 1994		
1147	35.0	
1156	35.0	
Oct 3, 1994		
1054	35.0	
Oct 11, 1994		
1038	34.8	
1049	34.8	
Oct 17, 1994		
1358	34.9	
Oct 21, 1994		
0919	34.6	
Oct 24, 1994		
1046	35.2	battery: 8.71 V
Oct 31, 1994		
1414	34.9	
1421	35.0	
Nov 8, 1994		
0950	34.8	
Nov 14, 1994		
1054	28.2	battery: 8.72 V
1328	28.2	@ synthetic data
1342	34.1	
1500	35.0	@ synthetic data
Dec 1, 1994		
1315	35.0	@ synthetic data
1316	35.5	
1333	35.2	
Dec 5, 1994		
1054	33.6	
1059	33.5	

Dec 9, 1994		
1317	33.8	
1324	33.9	
1330	33.9	
1335	27.8	
1337	29.5	
1340	31.4	
1342	32.7	
1345	32.9	
1346	32.9	
1348	32.9	
1350	32.9	
1352	33.0	
1354	32.9	
1356	32.9	
Dec 12, 1994		
1037	33.7	
1043	33.8	
Dec 13, 1994		
1445	34.9	
Dec 16, 1994		
1327	34.2	battery: 8.18 V
1346	31.4	
1350	32.4	
1353	33.8	
1354	33.8	
1400	33.8	
Dec 27, 1994		
1051	34.3	
1058	34.4	
Jan 3, 1995		
1424	34.7	
1424	34.8	
1441	34.8	
Jan 9, 1995		
1112	34.6	battery: 8.28 V
1113	34.7	
Jan 10, 1995		
0953	33.9	
1001	33.8	
Jan 17, 1995		
1320	33.8	
1322	33.9	
1330	34.1	
1334	34.1	
1337	34.0	
Jan 23, 1995		
1339	35.1	
1347	35.2	
1356	35.2	
Jan 30, 1995		
1421	32.7	

Jan 31, 1995	
1421	28.2
1356	30.2
1407	30.3
1420	30.4
1600	34.5 @ synthetic data
Feb 6, 1995	
1109	34.5
1116	34.6
Feb 13, 1995	
1126	34.2
1133	34.2
Feb 21, 1995	
1129	34.6
1137	34.6
1452	33.6
1600	34.6 @ synthetic data
Feb 27, 1995	
1051	34.8
1100	34.9
Mar 6, 1995	
1113	35.3
1124	35.3
Mar 13, 1995	
1400	34.9
Mar 15, 1995	
1047	35.0
1113	35.1
Mar 17, 1995	
0920	34.4
1010	34.9
Mar 20, 1995	
1331	35.2
1338	35.2
Mar 27, 1995	
1414	34.9
1424	34.7

Mar 31, 1995		
0936	33.3	battery: 7.94 V
0939	33.5	
0941	33.6	
0944	33.8	
0947	34.0	
0954	34.2	
1009	34.3	
1010	34.4	
1013	34.5	
1013	28.8	
1017	33.9	
1018	34.3	
1020	34.6	
1022	34.5	
1026	34.5	
1028	34.4	
1032	34.4	
1037	33.6	
1038	34.1	
1039	34.6	
1040	34.7	
1042	34.8	
1043	34.6	
1045	34.5	
Apr 3, 1995		
1040	35.0	

APPENDIX I. BATTERY VOLTAGE RECORDS FROM FIELD NOTES

In this appendix, figure I-1 is a graph showing the average voltage on the four 12-V batteries used to power the various Morris systems. Voltages were recorded by hand using a voltmeter. Voltage data were only recorded at the beginning and ending of each data file; the graph shows straight line interpolation between the data points. Therefore, the data cannot be used quantitatively for removing voltage correlated waveforms; but the graph can be used qualitatively to analyze overall trends and to help determine whether artifacts of voltage fluctuations may be present in the gradient data.

As a result of the action of the solar panels, the battery voltages fluctuated between 12 V and 16 V. Testing showed that the system's direct response to these fluctuations did not produce more than about 0.08 nT/m rms of gradient noise (see Table 1CC) in the data. This result was typically observable (under test conditions) only when the voltages of all four batteries were varied simultaneously. Hence figure I-1 graphs the average voltage rather than selected individual-battery voltages.

It is thought that variations in the battery voltages may have affected the temperature holding ability of Morris. The destabilized temperature would then have had a larger effect on the gradient data than the direct response. Therefore, battery voltage variations may be indirectly correlated to gradient noise through Morris-temperature variations.

Table I-1 (following figure I-1) is simply a listing of the dates, times (in hours and minutes), and battery-voltage values extracted from the field notes. Battery-voltage related notes are given in intervening lines.

Figure I-1. Average voltage of all four power batteries. Voltages were taken from the field notes.

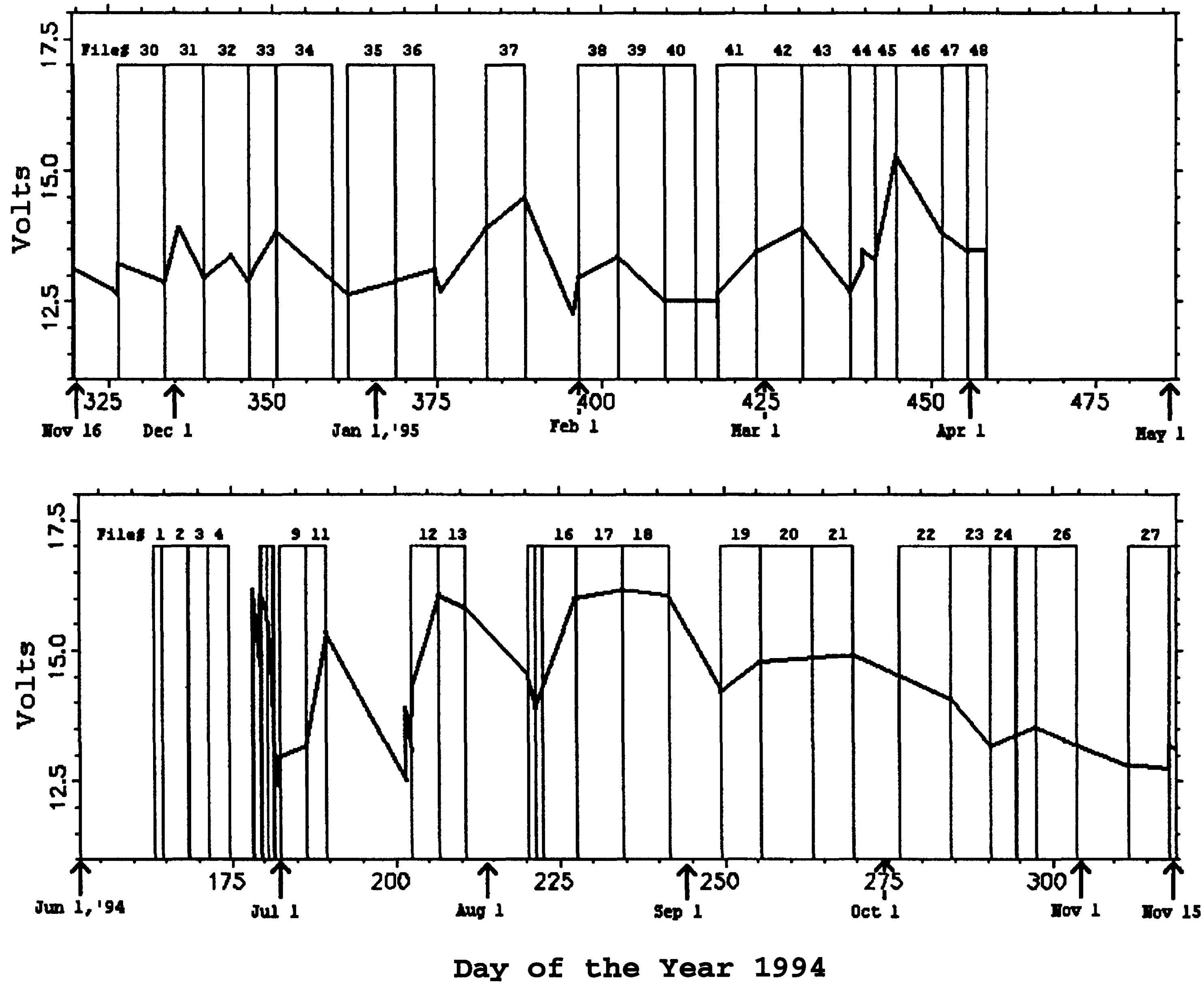


TABLE I-1: BATTERY VOLTAGE DATA

DOY94 - The date and time of the voltage reading or note expressed as the decimal day of the year 1994. The form of this date has been made for easy reference to the data coverage bar graph and to appendix F.

DATE - The month and day of the month. Jun - Dec are in the year 1994; and Jan - Mar are in the year 1995.

HH:MM - The hour and minute of the day on a 24-hour clock, Hawaii Standard Time (-10 hours from UTC)

BATTERY: - Indicates the the following column headers are battery functions: PC, TED, DASL, DASH.

PC - The battery serving the data acquisition computer

TED - The battery serving the Morris-temperature holding circuitry.

DASL - The data acquisition system low battery (0-12 V).

DASH - The data acquisition system high battery (12-24 V).

DOY94	DATE	HH:MM	BATTERY: PC TED DASL DASH
178.546	Jun 27,	13:06	VOLTAGE: 16.24, 16.20, 16.15, 16.14
179.415	Jun 28,	09:57	VOLTAGE: 16.07, 16.17, 13.47, 13.24
179.415	Jun 28,	09:57	Panel: 16.22, 16.50, 13.59, 13.31
179.626	Jun 28,	15:01	VOLTAGE: 16.09, 16.16, 16.08, 15.96
180.483	Jun 29,	11:36	VOLTAGE: 15.66, 16.22, 16.00, 15.35
181.399	Jun 30,	09:35	VOLTAGE: 13.40, 16.47, 13.65, 13.20
181.399	Jun 30,	09:35	(BATT for TE high because no pwr
181.399	Jun 30,	09:35	used thru night?)
181.415	Jun 30,	09:58	Turned main pwr switch off, disconn
181.415	Jun 30,	09:58	then reconn BATT
181.415	Jun 30,	09:58	VOLTAGE: 13.51, 13.80, 13.33, 13.15
181.433	Jun 30,	10:23	Computer BATT with panel: 13.58 V
181.438	Jun 30,	10:31	TED BATT: 12.76 V
181.626	Jun 30,	15:01	VOLTAGE: 12.70, 12.70, 12.69, 12.54
182.389	Jul 1,	09:20	VOLTAGE: 12.43, 12.55, 12.44, 12.36
182.421	Jul 1,	10:06	Hooked up solar panels to computer
182.421	Jul 1,	10:06	and DAS BATTs
182.421	Jul 1,	10:06	VOLTAGE: 12.69, 12.64, 12.90, 12.63
182.433	Jul 1,	10:23	VOLTAGE: 13.14, 12.65, 13.18, 13.03

186.424	Jul 5, 10:11	VOLTAGE: 13.25, 12.59, 13.45, 13.35
186.424	Jul 5, 10:11	Checked water levels, put some water
186.424	Jul 5, 10:11	in PC BATT
189.538	Jul 8, 12:55	VOLTAGE: 16.33, 12.57, 16.30, 16.20
201.455	Jul 20, 10:55	VOLTAGE: 11.91, 12.53, 12.85, 12.73
201.455	Jul 20, 10:55	VOLTAGE: 12.63, 13.40, 14.56, 15.07
202.376	Jul 21, 09:02	VOLTAGE: 12.34, 14.44, 13.21, 13.02
202.385	Jul 21, 09:15	Switched computer and TED BATTs
202.385	Jul 21, 09:15	Filled water in all BATTs
202.390	Jul 21, 09:21	VOLTAGE: 13.62, 12.22, 13.29, 13.13
202.401	Jul 21, 09:37	TED BATT: 12.17 V
202.557	Jul 21, 13:22	Replaced TED BATT
202.557	Jul 21, 13:22	VOLTAGE: 15.80, 14.50, 13.73, 13.54
202.557	Jul 21, 13:22	Old TED BATT: 12.53 V - no load
206.558	Jul 25, 13:23	VOLTAGE: 16.10, 15.80, 16.22, 16.19
210.675	Jul 29, 16:12	VOLTAGE: 16.09, 15.74, 16.19, 15.36
210.681	Jul 29, 16:20	Filled water in BATTs
220.443	Aug 8, 10:38	VOLTAGE: 13.66, 16.24, 14.22, 13.97
220.454	Aug 8, 10:54	Filled water in BATTs
221.385	Aug 9, 09:14	VOLTAGE: 13.26, 15.50, 13.48, 13.31
227.503	Aug 15, 12:05	VOLTAGE: 15.73, 16.01, 16.11, 16.13
234.576	Aug 22, 13:50	Filled water in BATTs
234.592	Aug 22, 14:13	VOLTAGE: 16.17, 15.87, 16.31, 16.29
241.590	Aug 29, 14:10	VOLTAGE: 16.15, 15.66, 16.19, 16.18
249.442	Sep 6, 10:37	VOLTAGE: 13.51, 16.05, 13.73, 13.63
249.442	Sep 6, 10:37	Filled water in BATTs
255.483	Sep 12, 11:36	VOLTAGE: 14.02, 15.97, 13.92, 15.27
263.460	Sep 20, 11:02	Filled water in BATTs
269.491	Sep 26, 11:47	VOLTAGE: 14.34, 15.57, 13.91, 15.80
284.443	Oct 11, 10:38	VOLTAGE: 13.54, 15.61, 13.43, 13.81
284.443	Oct 11, 10:38	Filled water in BATTs
284.451	Oct 11, 10:49	Disconnected one solar panel from
284.451	Oct 11, 10:49	temperature supply
284.451	Oct 11, 10:49	BATT now 15.10 V
290.582	Oct 17, 13:58	VOLTAGE: 12.66, 14.34, 12.78, 12.91
297.449	Oct 24, 10:46	VOLTAGE: 13.30, 14.38, 12.93, 13.55
297.455	Oct 24, 10:55	Filled water in BATTs

304.593	Oct 31, 14:14	Water in BATTs okay
312.410	Nov 8, 09:50	VOLTAGE: 12.58, 13.52, 12.35, 12.77
318.454	Nov 14, 10:54	VOLTAGE: 12.60, 13.92, 11.95, 12.61
318.454	Nov 14, 10:54	Probable bad BATT,
318.454	Nov 14, 10:54	didn't restart KMGS9
318.555	Nov 14, 13:19	Replaced one BATT (12 out of
318.555	Nov 14, 13:19	24 V system): 13.43 V
318.555	Nov 14, 13:19	VOLTAGE: 12.96, 13.01, 13.94, 12.91
325.583	Nov 21, 14:00	VOLTAGE: 12.50, 13.94, 12.43, 12.03
326.403	Nov 22, 09:40	Changed computer 12 V BATT,
326.403	Nov 22, 09:40	installed computer
326.403	Nov 22, 09:40	VOLTAGE: 13.40, 13.33, 12.13, 11.69
326.403	Nov 22, 09:40	Replaced both DAS BATTs
326.403	Nov 22, 09:40	VOLTAGE: 13.21, 13.27, 13.35, 13.09
333.468	Nov 29, 11:14	VOLTAGE: 12.65, 13.48, 12.71, 12.67
335.553	Dec 1, 13:16	Multiplexer BATT: 12.72 V
335.553	Dec 1, 13:16	Installed multiplexer on
335.553	Dec 1, 13:16	TEMP 4 cable, hooked up
335.553	Dec 1, 13:16	Multiplexer BATT: 12.73 V
335.553	Dec 1, 13:16	Covered connectors, MUX, and BATT
335.553	Dec 1, 13:16	with plastic
335.565	Dec 1, 13:33	VOLTAGE: 14.52, 14.80, 13.15, 13.23
339.458	Dec 5, 10:59	VOLTAGE: 12.96, 13.45, 12.60, 12.85
343.553	Dec 9, 13:17	VOLTAGE: 13.39, 14.23, 12.76, 13.20
343.553	Dec 9, 13:17	Duplexer BATT: 12.54 V
346.447	Dec 12, 10:43	VOLTAGE: 12.98, 13.56, 12.22, 12.76
347.615	Dec 13, 14:45	VOLTAGE: 14.44, 13.83, 12.40, 12.48
347.615	Dec 13, 14:45	Replaced BATT in 12 of 24 V system
347.615	Dec 13, 14:45	VOLTAGE: 14.00, 13.84, 12.76, 12.48
347.615	Dec 13, 14:45	Discovered reason 24 V system
347.615	Dec 13, 14:45	voltages dropping: bottom 3 out
347.615	Dec 13, 14:45	of 4 24 V system solar panels in
347.615	Dec 13, 14:45	shade from tree during afternoon
350.563	Dec 16, 13:31	VOLTAGE: 13.53, 14.56, 13.43, 13.83
350.563	Dec 16, 13:31	Duplexer BATT: 12.48 V
361.455	Dec 27, 10:55	VOLTAGE: 12.58, 13.61, 11.93, 12.41
361.457	Dec 27, 10:58	Panel for #3 BATT reads 12.00 V
361.457	Dec 27, 10:58	Removed brush shading panel
361.457	Dec 27, 10:58	Wired extra solar panel to #3 BATT
361.457	Dec 27, 10:58	#3 BATT: 12.31, panels read 12.60 V

368.606	Jan 3, 14:32	VOLTAGE: 12.63, 13.38, 13.55, 12.01
368.606	Jan 3, 14:32	Switched solar panels on 24 V sys,
368.606	Jan 3, 14:32	put 3 panels on weak BATT
368.606	Jan 3, 14:32	BATTs 3 & 4: 13.22, 12.12 V
374.467	Jan 9, 11:13	VOLTAGE: 12.62, 13.09, 12.76, 14.08
374.467	Jan 9, 11:13	Switched solar panel banks for #3
374.467	Jan 9, 11:13	& #4 BATTs, 3 panels on #3 BATT,
374.467	Jan 9, 11:13	2 panels on #4 BATT
375.413	Jan 10, 09:55	VOLTAGE: 12.41, 12.86, 12.76, 12.75
375.413	Jan 10, 09:55	Multiplexer BATT: 12.29 V
382.556	Jan 17, 13:20	VOLTAGE: 12.90, 14.07, 15.36, 13.41
382.556	Jan 17, 13:20	(First BATT is for computer, seems a
382.556	Jan 17, 13:20	little low, maybe went too low
382.556	Jan 17, 13:20	for computer and caused problem
382.556	Jan 17, 13:20	weather is sunny now- may have
382.556	Jan 17, 13:20	been cloudy over the last week)
388.574	Jan 23, 13:47	VOLTAGE: 13.60, 14.75, 15.63, 14.00
388.574	Jan 23, 13:47	Moved 3-panel array to first BATT
388.574	Jan 23, 13:47	(for computer)
395.598	Jan 30, 14:21	VOLTAGE: 11.94, 13.10, 12.45, 11.67
395.598	Jan 30, 14:21	BATTs are low, probably why computer
395.598	Jan 30, 14:21	went out
396.598	Jan 31, 14:21	Replaced low BATTs
396.581	Jan 31, 13:56	VOLTAGE: 13.14, 12.67, 13.19, 12.99
396.588	Jan 31, 14:07	Installed 10W solar panel for
396.588	Jan 31, 14:07	multiplexer BATT
402.465	Feb 6, 11:09	VOLTAGE: 13.52, 13.42, 13.28, 13.20
402.469	Feb 6, 11:16	Multiplexer BATT with panel: 12.74 V
402.469	Feb 6, 11:16	BATT w/o panel: 12.69 V
409.476	Feb 13, 11:26	VOLTAGE: 12.61, 12.51, 12.56, 12.32
409.481	Feb 13, 11:33	3-panel solar array on computer BATT
409.483	Feb 13, 11:35	DAS BATTs have low indicator on
417.478	Feb 21, 11:29	VOLTAGE: 12.81, 13.01, 12.39, 11.86
417.484	Feb 21, 11:37	Duplexer BATT w/panel: 14.76 V
417.603	Feb 21, 14:28	VOLTAGE: 12.45, 12.76, 12.04, 11.49
417.603	Feb 21, 14:28	Installed new BATTs for DAS
417.603	Feb 21, 14:28	Switched fan and computer BATTs
417.603	Feb 21, 14:28	VOLTAGE: 12.66, 12.57, 12.68, 12.74
417.603	Feb 21, 14:28	Computer power glitched out during
417.603	Feb 21, 14:28	BATT switch
423.452	Feb 27, 10:51	VOLTAGE: 13.87, 13.21, 13.44, 13.32
430.467	Mar 6, 11:13	VOLTAGE: 14.06, 14.57, 13.59, 13.37
437.583	Mar 13, 14:00	VOLTAGE: 12.67, 13.37, 12.39, 12.28

439.449	Mar 15, 10:47	VOLTAGE: 13.28, 14.40, 12.72, 12.62
439.449	Mar 15, 10:47	Replaced DAS BATTs
439.449	Mar 15, 10:47	VOLTAGE: 12.93, 13.74, 13.54, 13.69
439.467	Mar 15, 11:13	Replaced computer BATT,
439.467	Mar 15, 11:13	now 15.11 V (with sun)
441.389	Mar 17, 09:20	VOLTAGE: 13.27, 13.26, 13.25, 13.40
444.563	Mar 20, 13:31	VOLTAGE: 15.44, 15.08, 15.39, 15.26
451.593	Mar 27, 14:14	VOLTAGE: 13.96, 14.71, 13.54, 13.03
455.400	Mar 31, 09:36	VOLTAGE: 13.57, 13.50, 13.50, 13.33

APPENDIX J. ABBREVIATIONS

Basic Units

A - ampere (current)
Ah - ampere-hour (quantity of electricity)
Btu - British thermal unit (energy)
cm - centimeter (length)
dB - decibel (ratio)
° - degree (arc or angle)
°C - degree Celsius (temperature)
°F - degree Fahrenheit (temperature)
ft - foot (length)
hr - hour (time)
Hz - hertz (frequency)
K - kilobyte (quantity of digital data)
kg - kilogram (mass, used here as weight)
kHz - kilohertz (frequency)
km - kilometer (length)
m - meter (length)
mA - milliampere (current)
Mb - megabyte (quantity of digital data)
mm - millimeter (length)
μcgs - millionth of a CGS unit (magnetic susceptibility)
μHz - microhertz (frequency)
μOe - micro-oersted (magnetic-field intensity)
μrad - microradian (arc)
μs - microsecond (time)
nT - nanotesla (magnetic induction)
R - hr·ft^2·°F/Btu (thermal resistance)
V - volt (potential difference)

Compound Units

dB/octave - decibels per octave (roll-off)
°C/V - degrees Celsius per volt (coefficient)
μrad/°C - microradians per degree Celsius (thermal stability)
nT/°C - nanoTeslas per degree Celsius (thermal stability)
nT/m - nanoTeslas per meter (magnetic-field gradient)
nT/m/m - nT/m per meter (magnetic-field curvature)
nT/V - nanoTeslas per volt (coefficient)

Miscellaneous

A/D - Analog-to-Digital
ASC - ASCII
BATT - battery
CNTRL - control key on a computer keyboard
DAS - Data Acquisition System
dc - Direct Current
/ - divided by, per, or a conjunction
^ - exponent
FTP - File Transfer Protocol
GMF - GeoMagnetic Field
HEX - hexadecimal
HVO - Hawaiian Volcano Observatory

INT - integer
1/f - inversely proportional to frequency
1/r^3 - inversely proportional to radius cubed
1/r^4 - inversely proportional to radius to the fourth power
KMGR - the data acquisition (C) program used Nov 16 - Apr 3
KMGS9 - the data acquisition (C) program used Jun 12 - Nov 15
MAG - magnetometer
MDS - Main Digital System
MELDIAG - (C) program for diagnostics on the TED control system
mo - month
Morris- the grey box housing the prototype TMGS' electronics
No. - number
MUX - multiplexer
p2p - Peak-to-Peak (error or amplitude)
PC - Personal Computer
± - plus or minus (error or amplitude)
RCM - Ring Core Magnetometer
rms - Root Mean Square (amplitude)
RS232 - serial-data transfer protocol
SQUID - Superconducting QUantum Interference Device
TE - ThermoElectric
TED - ThermoElectric Device or ThermoElectric Device system(s)
TEDCNT7 - a previous version of TEDCNT8
TEDCNT8 - (Fortran) program used in the palm-top for TED control
TEMP - temperature
TESSA - Tetrahedral Electromagnetic-Sensor Suspension Apparatus
TMGS - Tensor Magnetic Gradiometer System
UTC - Universal Time, Coordinated