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Data collection and reduction procedures for 1900 km of total intensity magnetic field data collected with a truck-mounted system in southeastern Arizona, southwestern Colorado, and northwestern Wyoming

by

Paul E. Gettings[1], Mark E. Gettings[1], and Mark W. Bultman[1]

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[1]U.S. Geological Survey, 406 Gould-Simpson Building, University of Arizona, Tucson, Arizona, 85721

Abstract

This report details the acquisition, reduction, and availability of total intensity magnetic field data collected with a truck-mounted magnetometer from selected regions of southeastern Arizona, southwestern Colorado, and northwestern Wyoming. This dataset is comprised of approximately 381,000 observations along about 1,900 line km of profiles. The dataset and the computer software used in the data reduction are available to users via anonymous FTP on the Internet or World Wide Web servers.

Data Acquisition, Reduction, and Accuracy

Data Acquisition

Total intensity magnetic field data were acquired from locations in southeastern Arizona, southwestern Colorado, and northwestern Wyoming (Fig. 1) during several field excursions, each lasting from a few days to several weeks in the period 1989 to 1993. Much of the Arizona data are located in the Santa Catalina, Galiuro, Santa Rita, and Patagonia Mountains, and the Tucson, San Rafael, and San Pedro basins. Colorado data were taken in the western San Juan Mountains in the Silverton Caldera area and on the Uncompahgre Plateau. The data from Wyoming come from the Wood River area including the Kerwin porphyry in the Absaroka Mountains. The reduced data are archived by year and the size and filename location of data from the various areas are shown in Table 1.

Data were collected by the use of a proton precession magnetometer (Geometrics airborne magnetometer, model G-811) mounted on a four-wheel drive utility vehicle, with an average sample spacing of 5 meters and a frequency of 1 reading per second. The magnetometer sensor is at a nominal height of 3.8 meters above the surface and 4.6 meters behind the truck. The sensor is compensated against magnetic effects from the truck and magnetic field variation due to heading. However, since the required compensation is a function of magnetic latitude, an additional software heading corrections is also done as part of the data reduction sequence described below. The compensation with software requires that the truck system be used to collect heading versus azimuth data at a magnetically quiet location within the survey area, thus saving the considerable effort required to physically recompensate the system before every survey. The magnetic data are collected onto a computer real-time along with one-dimensional position data, and documentation points used to precisely locate in the dataset features such as navigation points, man-made magnetic sources such as culverts and power lines, and geologic features. The data recorded also include the time of each observation to the nearest second and a fixed 8 character numeric string set by thumbwheel switches which uniquely identifies each dataset. The collected data are written onto floppy diskette media for processing in the office. The data collection configuration is illustrated in Figure 2.

Data Reduction

The raw magnetic and one-dimensional position data are reduced by first deleting all extraneous readings (e.g., those caused by large volumes of iron, such as bridges, and faulty readings originating from errors in the data acquisiton system), then interpolating the geographic location, interpolating the altitude of the readings, and, finally, subtracting the International Geomagnetic Reference Field, diurnal drift, and heading error. Figure 3 summarizes the data reduction process from diskette files recorded in the truck to a final archive dataset. The removal of extraneous data is accomplished by removing those points with observed field readings outside the range of 20,000

- 70,000 nanoTesla (nT). Points which have position data changes of greater than 24 meters are also discarded. A position change of 24 meters in one second corresponds to a ground speed of 60 miles per hour, and thus indicates an extraneous point as the system is typically operated at speed of 5-15 mph. Because the system experiences large accelerations when operating on rough roads, there are sometimes erroneous observations due to such things as loosened connections, etc. in the system. These points have magnetic field and/or position values that generally plot off of the graph of possible values (see Fig. 4a for some examples of these "photon torpedoes" and the effect of bridges and cattle guards). Figure 4b illustrates a typical data profile after this cleaning process.

The horizontal position interpolation (georeferencing) is accomplished by digitization (from 1:24,000 scale topographic maps) of the track taken by the truck. A linear interpolation of the latitude and longitude is then accomplished by matching the known positions on the road against known positions in the data (called "documentation points"). The software section, below, has a more detailed description of how this interpolation is accomplished.

Elevation interpolation is accomplished using the U.S. Geological Survey digital 3 arc-second elevation models created from 1:250,000 scale topographic maps. The interpolation is linear in both x and y, based on the interpolated latitude and longitude of each data point.

Data correction consists of forming the residual anomaly by subtracting the IGRF and then performing diurnal drift and heading corrections to the residual. The IGRF is calculated using the DIGRF program (Peddie and Zunde, 1990) available from the National Geophysical Data Center in Boulder, Colorado. The coefficients presently being used are from 1985. The diurnal drift correction is accomplished by interpolation of the drift derived from a base station magnetometer. Ideally, these data are obtained from a base station operated in the survey area during the data collection period. For the work described here, no base station magnetometer was available and so geomagnetic observatory data from one minute samples taken at the Boulder, CO, or Tucson, AZ magnetic observatories for the times required were used to estimate the diurnal drift. Heading corrections are done by using a linear interpolation of the correction as a function of heading. The correction as a function of heading is created by measuring the time-averaged field at the same position while changing the heading of the truck. The headings are based on degrees from true north. For the profile data, the heading is computed from the latitude-longitude locations of the current and previous data point.

With the exception of the removal of off-scale points and points where the magnetometer malfunctioned, the corrected data are not smoothed or filtered and all magnetic sources appear in the data. Field notes, which refer to documentation points in the digital data record (described below), are kept on file which document the locations of items important to the analysis of the data, including man-made magnetic sources such as power lines, culverts, and bridges. These field notes are available from the authors upon request.

Data Accuracy

Horizontal position precision is generally within 10 meters. This is derived from the accuracy of the digitization of 1:24,000 scale topographic quadrangle maps which are used to interpolate the position of the data from the recorded one-dimensional position. Vertical location precision varies between 50 feet in flat terrain to 200 feet in steep terrain (Elassal and Caruso, 1983). Observed magnetic field data is precise to one hundredth of a gamma, but due to the low altitude of the sensor and the resulting high variation, accuracy is probably only good to about 5 nanoTesla (nT). Residual and corrected field readings are also only good to 5 nT. Time data are generally accurate to one second relative to Greenwich Mean Time.

Reduced Data Format

Data File Format

Reduced data files are all in the Truck Magnetic Data (TMD) format as specified below. The TMD format consists of a series of newline-terminated records comprising one reading each. Each record has 14 fixed-width columns into which the data is divided. The file is in ASCII characters. The meaning and width of each column, in characters, is below:

Column	Width	Data
1	3	Latitude degrees
2	3	Latitude minutes
3	5	Latitude seconds * 100
4	5	Longitude degrees
5	3	Longitude minutes
6	5	Longitude seconds * 100
7	7	Elevation, meters
8	8	Observed field * 100, nT
9	9	Residual field * 100, nT (observed-IGRF)
10	9	Corrected residual field * 100, nT
11	4	Document point #
12	3	Year - 1900
13	4	Day of the year (1 - 366)
14	6	Second of the day (0 - 86,400)

The data is divided by year, with one file containing all data taken during the year. All data is available through anonymous FTP at strider.tfo.arizona.edu (128.196.24.42):/pub/open_file/truckmag.

FTP Site Structure

Data files by year are stored in the /pub/open_file/truckmag directory on the FTP site. The subdirectory "docs" contains the UNIX-style man pages for the software reduction programs and ASCII and Postscript versions of this report. The software source code used for data reduction are placed, in ASCII format, in the subdirectory "src".

Software Description

General Description

The software used in the collection and processing of the magnetic data is all available via anonymous FTP from the same location as the data itself. The software is stored under the directory /pub/open_file/truckmag/src. Each program is placed in the sub-directory of its name. The reduction programs are complete with UNIX Makefiles. All reduction programs are written in ANSI C or Fortran (F77) and should compile on compilers which support ANSI standards. The software runs on SUN UNIX computers with SUN's ANSI compilers.. The real-time data acquisition program can only be compiled under Borland Turbo C v2.0 running under DOS, and requires the presence of the National Instruments GPIB Turbo C libraries and header files. Figure 3 shows a summary flow chart of the programs of the reduction system and a description of each reduction program, along with the method of use is given below. The data acquisition program is not included as it is specific to the instrumentation used in the truck. Figure 4 shows a typical profile a) as recorded in the truck, b) after cleaning, and c) after completion of the reduction procedure. Note in Fig. 4c that the residual anomaly is plotted as a function of distance projected to an azimuth and thus is a derived value from the latitude-longitude values of the final reduced data.

tmagcnvrt

tmagcnvrt takes as input the binary packed file from the first generation truck computer (1989) and translates it into the ascii file format similar to the one used in the current computer (a 24 character wide string). The output of **tmagcnvrt** is fed into **oldmag_clean** for cleaning and further translation.

oldmag_clean

oldmag_clean is used to unpack the ascii files created by **tmagcnvrt**. The files are unpacked into the ascii format expected by the other reduction programs. **oldmag_clean** also calculates the time (in seconds) of each reading from the supplied **mark time** of the specified **document point** (doc point). The time is from midnight GMT of the current day, and so the offset to GMT is required and asked for by the program. In the event of day changes in GMT, the day is incremented and the seconds restart. The day and year are taken from the thumbwheel settings present in the packed raw data file. The output file is an ascii data file with the field reading, x-counter value, and time/date for each reading. Invalid data (such as fields that are outside the known extrema) are removed, unless the doc point value changes, in which case the record is preserved for geo-referencing purposes.

newmag_clean

newmag_clean performs the same functions as oldmag_clean, but it is used for the data format used from 1990-1994. The data is stored as an ascii string with the time and date included in the file. The thumbwheel settings are removed from each record and are written once at the head of the raw data file. **newmag_clean** requires the offset from GMT, but not a **mark time** as the time is read directly from the file. The output file is the same as for **oldmag_clean**.

mag_georef

mag_georef takes the cleaned data file from either **oldmag_clean** or **newmag_clean** and interpolates the latitude and longitude of each reading from the supplied digitized road file. The road file is created from the field maps and is a point digitization of the data track. The road file points are considered to be the endpoints of a straight line segment which is the road. The format of the road file is given below. All fields are space delimited.

UTM Easting UTM Northing Deg Min Sec Deg Min Sec Doc_Point_#
- Longitude - -- Latitude --

Only the latitude/longitude values are used. The coordinates of each data point are calculated from the X-counter value of the record and the road file points. A straight linear interpolation of an X-counter value for every road point (based on the value of the X-counter at known doc points in the road file) is then used to linearly interpolate the position (in deg., minutes, and seconds) of each data record from the X-counter value of the data record. The interpolated position of the record is then written to the standard fields of the data file.

The road file used for georeferencing must conform to the standard printed above and explained here. The UTM Easting and Northing are unused coordinates stored in kilometers. The latitude and longitude are space-separated fields of degrees, minutes, and seconds. The seconds are stored to the hundredth of a second. The Doc_Point_# is a 12-character wide field that holds the doc point number of the road point. If there is no number, the field is filled with spaces. These doc points are used by **mag_georef** to match known road file points and data points. Since doc points are recorded on the map and in the data, the exact position is known from the digitization. Thus, it is imperative that the road file have as many of the known doc points as possible. It is also necessary that the road file have a sufficient point density so that curves and such in the road are accurately described by the straight line segments of the file.

mag_altitude

mag_altitude uses U.S. Geological Survey 1x1 degree digital elevation models (DEM) to interpolate the elevation of each data record. The elevation is interpolated from the lat./lon. position supplied by **mag_georef**. Every point which is inside the boundaries of the DEM supplied to the program is interpolated. Those points which lie outside the coverage of the DEM are left unchanged from their initial values (normally 0). The interpolated data file can then be rerun with another DEM to fill in any gaps which might have occurred. The format and standards of 1x1 degree DEMs are specified in the Geological Survey Circular 895-B. The interpolated elevations of the data points are known to be accurate to 100 feet.

mag_correct

mag_correct is used to subtract the igrf and apply diurnal and heading corrections from the observed data. The reference field is obtained from the base station data, in this case from geomagnetic observatories maintained by the USGS. Heading corrections are performed by a linear interpolation of the correction factor as a function of heading measured from true north. The effect of the heading is found by measuring the magnetic field over the same location with the vehicle pointed in varying directions. Locations chosen for this measurement should have low magnetic noise to allow for stable field readings over a period of several measurements. The diurnal and heading correction is applied after the subtraction of the igrf.

The final result after diurnal and heading correction and the subtraction of the igrf is taken to be the final, corrected data. **mag_georef** writes these values out into the final output file along with the position, elevation, time, and date of the readings. The final output file conforms to the TMD format specified previously.

Software Use

All of the reduction programs take no command-line arguments; instead they use prompts from within the program. The following sub-sections merely detail the expected response to the program's prompts.

tmagcnvrt

tmagcnvrt has two prompts: the input file name and the output file name. Both prompts will not accept any sort of wildcard filenames. The visible output of the program is a listing of the thumbwheel settings, the indicated length of the data file, and the number of records written to the output file. If the latter two are not the same, then something has gone wrong.

oldmag_clean

oldmag_clean requires five inputs: the input file (from **tmagcnvrt**), the output file, the doc point number of the mark time, the mark time, and the number of hours to get GMT. The file prompts will not accept any wildcard inputs. The doc number is entered as a normal integer, with no padding. Mark times are entered as a 6-digit number formed by concatenating the hour, minutes, and seconds into one string without the colons (i.e. 10:21:05 -> 102105). The program then displays the date of the data (as indicated by the file) and the number of records written to the output file.

newmag_clean

newmag_clean requires the input of the input file, the output file, and the offset from GMT (entered as the number of hours to add to get GMT). The input and output files may not have wildcards in them of any sort. The program then reports the thumbwheel settings and the dates for the data (as indicated in the file). The final number of records written is also printed.

mag_georef

mag_georef is a highly interactive program with input required in several stages. The first input is the input filename (no wildcards allowed). The digitized road file (see above for the format) is required next. The program displays the number of data records in and the number of road point read. Any duplicate positions in the road file are reported and removed (the repeat position only). The program then asks if the doc point matches and factors should be recorded to a file as well as displayed on the screen. If the doc point matches and factors are to be recorded in a file, the program asks for the filename. The program then calculates the factors between matching doc point numbers. The factor is the change in x-counter counts divided by the distance down the road. The on-screen instructions indicate the correct factor ranges and values. The program asks for the match number (not doc point number) to stop the referencing. This is to allow for partial referencing of a file. Only the referenced points are written to the output file. The referencing begins with the first matching doc point. The program then prints the number of data points in the geo-referenced file and in the original data file. The output filename is prompted for (no wildcards allowed) and the data written.

mag_altitude

mag_altitude requires three inputs: the input file, the output file, and the DEM for the input file. The program then runs and interpolates the altitudes for each data point based on the position. The output file is written and the number of processed records is displayed. Any error messages are also printed. Occasionally a single data file will extend over more than one DEM coverage. In that case, the records which are outside of a given DEM's coverage are untouched and output as they were in the input file. These records can then be filled in by re-running mag_altitude with the proper DEM to provide coverage for the necessary area.

mag_correct

mag_correct takes multiple inputs, depending on the corrections desired. It always needs the names of the input and output files. If the diurnal correction with the base station field is desired, then answer yes to the prompt for diurnal correction and enter the name of the data file containing the base station data. The base station data must be in the format specified below. **mag_correct** can also perform a heading correction based on the heading of the truck between two points and the known variation induced by heading changes. If heading corrections are to be done, then answer yes to the prompt for heading correction and enter the filename of the heading variation data. The format of this file is given below.

Base Station Data Format

Base station data is contained in a 400 byte record consisting of 60 one-minute interval readings, one one hour average reading, and a header with the date, time and position of the observatory. The record is organized as follows:

Byte	Data
1-6	North Polar Distance (in thousandths of a degree)
7-12	Distance East from Greenwich (in thousandths of a degree)
13-14	Year
15-16	Month
17-18	Day
19	"F" - Type code to indicate total field measurements
20-21	Hour
22-24	Observatory abbreviation (3 letters)
25	"G" - Origin letter (G = Geological Survey)
26-34	Blanks
35-394	One minute readings in 6 character-wide fields
395-400	Hour average of all 60 readings

The data format above is obtained from the magnetic observatories. However, only the "F" records are kept, and the "D", "H", and "Z" records are removed. This is to get only the total field readings in the file.

Missing data is padded with 99999 to allow for fixed length records. More information is available about the format from the National Geophysical Data Center, Boulder, Colorado.

Heading Correction Data Format

The data format is 2 10-character wide (excluding decimal point) floating point numbers with implicit spaces. The first is the azimuth, and the second is the correction value, in nT. There can be no more than one heading correction value per degree.

References

Elassal, A.A., and Caruso, V.M., 1983, Digital Elevation Models, *in* McEwen, R.B, Witmer, R.E., and Ramey, B.S., USGS Digital Cartographic Data Standards: U.S. Geological Survey Circular 895-B, 40 p.

Peddie, N.W., and Zunde, A.K., 1990, Magnetic models for the United States for 1985:U.S. Geological Survey Circular C 1039, 26p.

Table 1. Summary table of the archived total intensity magnetic field data described in this report stored on computers at the Southwestern Field Office of the Branch of Western Mineral Resources, U.S. Geological Survey, in Tucson, Arizona.

State	Line km	# records	ftp source filename
WY	80	16229	93_data
AZ	1240	248646	89_data, 90_data, 92_data
CO	580	116124	91_data, 93_data
Total	1900	380999	

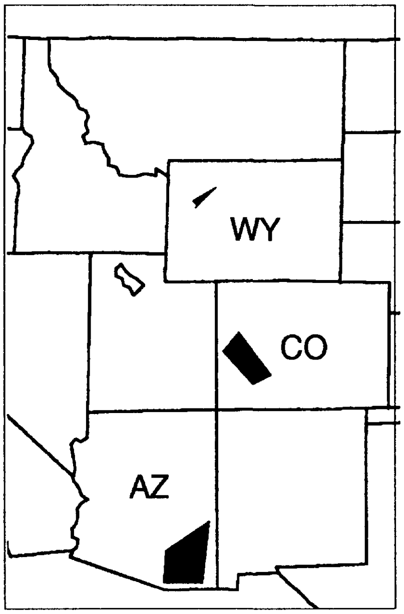

Figure 1. State outline map showing areas (shaded) where truck-mounted magnetometer data described in this report are available.

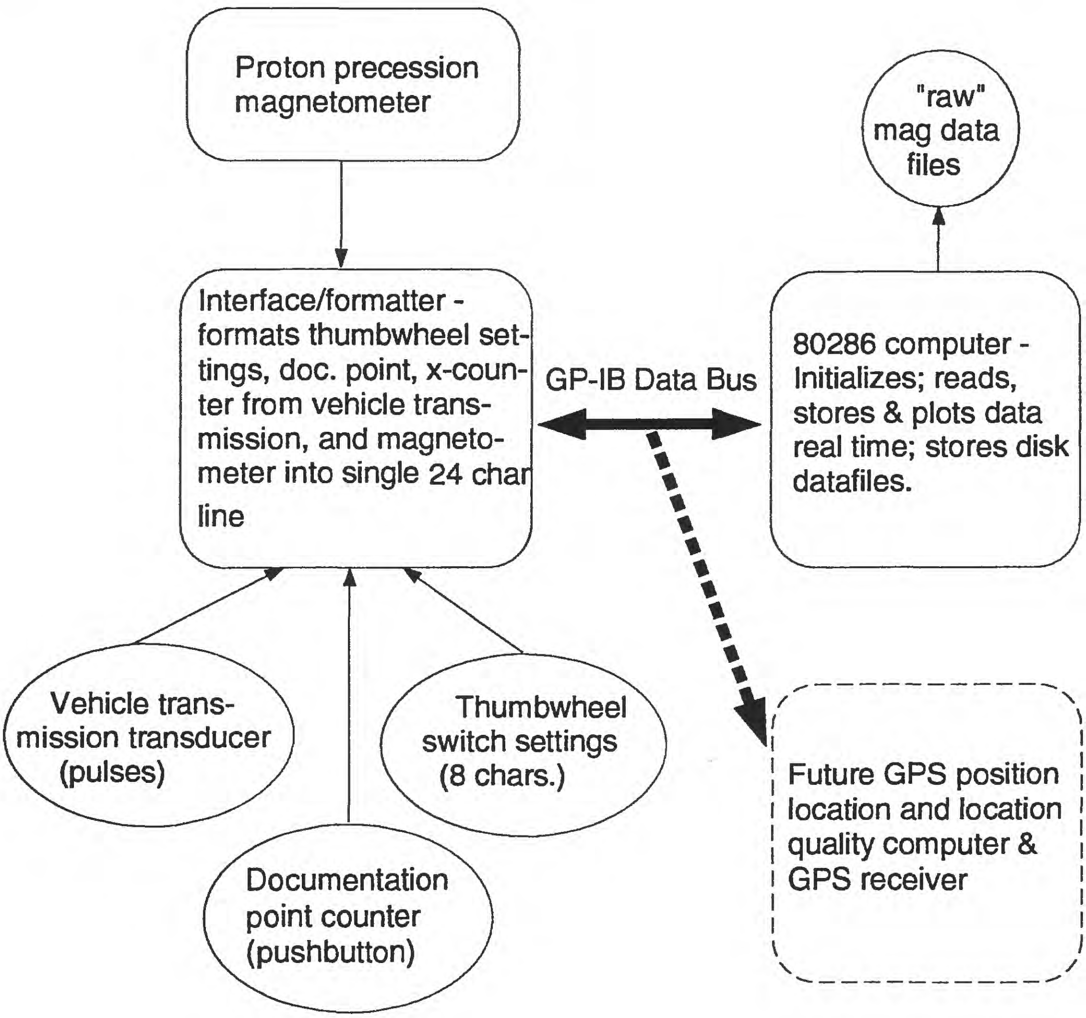

Figure 2. Photograph of the USGS truck-mounted magnetometer and block diagram showing data flow and collection scheme. "Raw" magnetic data files are the output and form the input to data reduction system shown in Figure 3.

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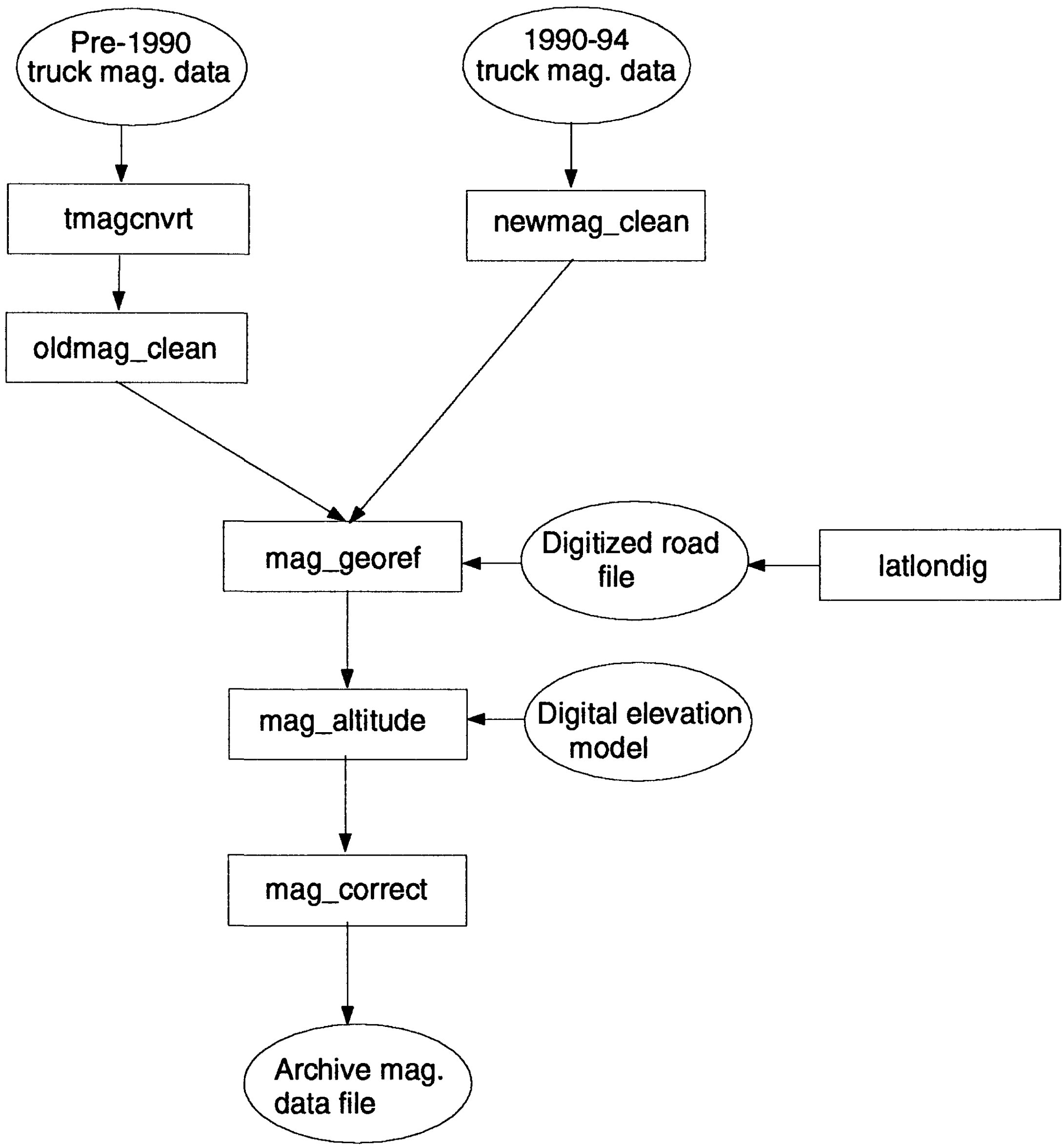

Figure 3. Flow chart showing data processing steps and the names of the important programs used in the reduction of truck-borne magnetometer data. Program latlondig is a general purpose program for digitizing map data into latitude-longitude point files.

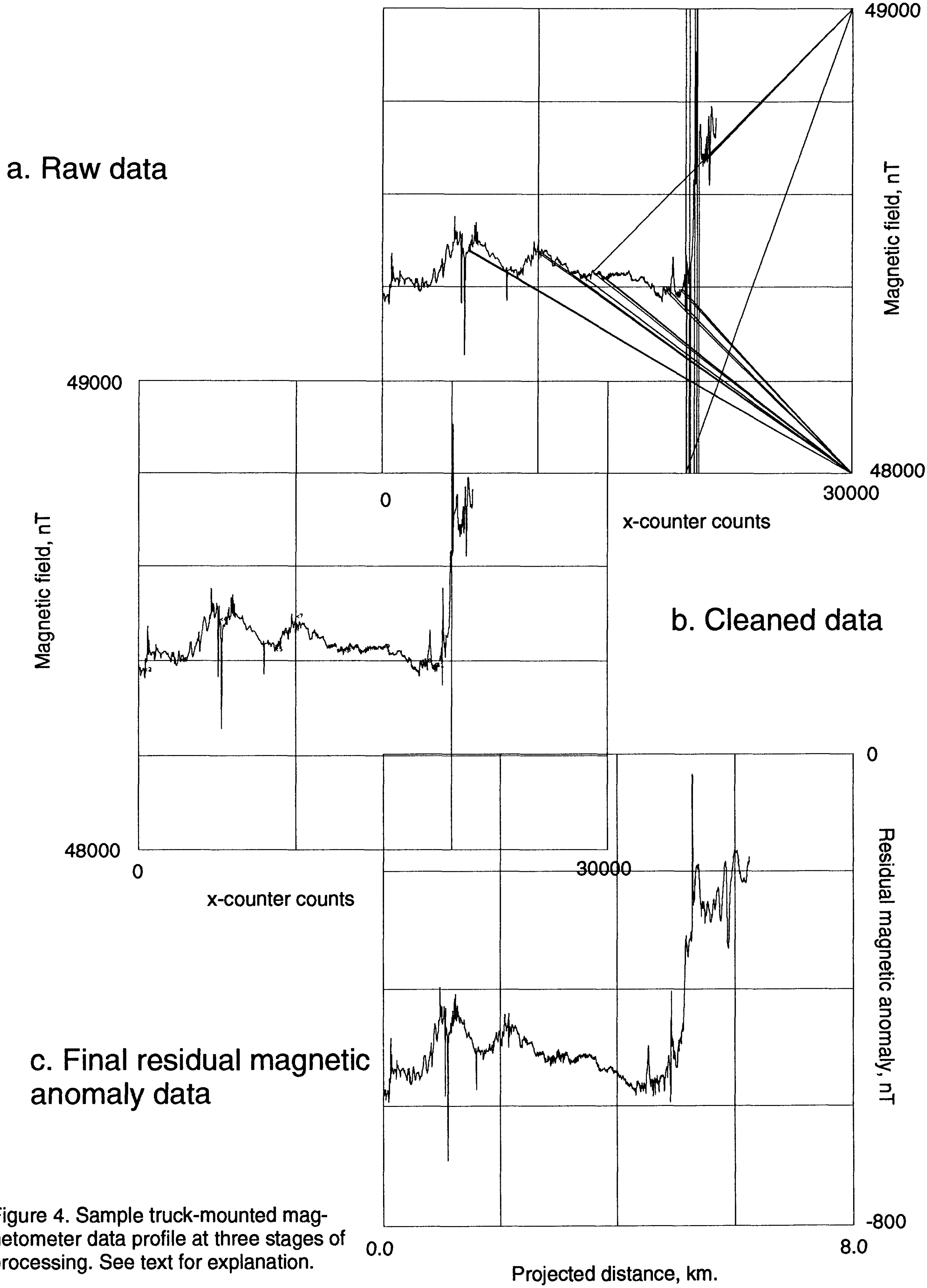

Figure 4. Sample truck-mounted magnetometer data profile at three stages of processing. See text for explanation.