UPmag: MATLAB software for viewing and processing u channel or other pass-through paleomagnetic data

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[1] With the development of pass-through cryogenic magnetometers and the u channel sampling method, large volumes of paleomagnetic data can be accumulated within a short time period. It is often critical to visualize and process these data in "real time" as measurements proceed, so that the measurement plan can be dictated accordingly. We introduce new MATLAB™ software (UPmag) that is designed for easy and rapid analysis of natural remanent magnetization (NRM) and laboratory-induced remanent magnetization data for u channel samples or core sections. UPmag comprises three MATLAB™ graphic user interfaces: UVIEW, UDIR, and UINT. UVIEW allows users to open and check through measurement data from the magnetometer as well as to correct detected flux jumps in the data, and to export files for further treatment. UDIR reads the *.dir file generated by UVIEW, automatically calculates component directions using selectable demagnetization range(s) with anchored or free origin, and displays vector component plots and stepwise intensity plots for any position along the u channel sample. UDIR can also display data on equal area stereographic projections and draw virtual geomagnetic poles on various map projections. UINT provides a convenient platform to evaluate relative paleointensity (RPI) estimates using the *.int files that can be exported from UVIEW. Two methods are used for RPI estimation: the calculated slopes of the best fit line between the NRM and the respective normalizer (using paired demagnetization data for both parameters) and the averages of the NRM/normalizer ratios. Linear correlation coefficients (of slopes) and standard deviations (of ratios) can be calculated simultaneously to monitor the quality of the RPI estimates. All resulting data and plots from UPmag can be exported into various file formats. UPmag software, data format files, and test data can be downloaded from http://earthref.org/cgi-bin/er.cgi?s=erda.cgi?n=985.

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1. Introduction

[2] The need to acquire remanent magnetization data at high resolution led to the development of pass-through cryogenic magnetometers for long core measurements [e.g., *Goree and Fuller*, 1976]. Aboard the R/V *JOIDES Resolution*, a system for measuring whole/half core sections has been operating for over 25 years, enabling magnetostratigraphic data to be generated from sediment cores. The u channel sample (which is typically enclosed in a transparent plastic tube with square 2×2 cm^2 cross section, and up to 150-cm length) was first advocated by *Tauxe et al.* [1983] to improve the spatial resolution associated with traditional discrete sampling. U channel samples have been increasingly employed in paleomagnetic studies on deep-sea and lake sediments since high-resolution pickup coils (with narrow width of response functions) and small diameter pass-through magnetometers were developed by 2G Enterprises and first installed at the paleomagnetic laboratory at Gif-sur-Yvette in France [*Weeks et al.*, 1993]. U channel sample measurement provides a resolution close to that obtained with back-to-back 8 cm^3 discrete cubic samples, after deconvolution, with the advantage of greater measurement speed and efficiency [*Nagy and Valet*, 1993; *Guyodo et al.*, 2002; *Roberts*, 2006].

[3] For u channel samples, the natural remanent magnetization (NRM) before and after stepwise demagnetization is routinely measured to recover directional variations of the geomagnetic field and to establish high-resolution magnetostratigraphies. The NRM normalized by laboratory-induced magnetizations such as the anhysteretic remanent magnetization (ARM), or isothermal remanent magnetization (IRM), is often used to estimate relative paleointensity (RPI) variation, although grain-size variation, shape and flocculation effects may complicate interpretations [e.g., *Levi and Banerjee*, 1976; *King et al.*, 1983; *Tauxe*, 1993]. Attempts have been made to reduce environmental (lithologic) influences using different normalization methods [e.g., *Brachfeld and Banerjee*, 2000; *Mazaud*, 2006]. It is routine to measure laboratory-induced magnetizations (ARM and IRM) and to compare the normalized intensities to find an optimal normalizer and RPI estimate. Additionally, these rock magnetic measurements provide records of the paleoenvironment, through concentration and grain-size-sensitive magnetic parameters.

[4] At the University of Florida (UF), we routinely measure NRM during demagnetization, followed by susceptibility, ARM during demagnetization and acquisition, and IRM during demagnetization for each u channel. The ARM is completely removed by demagnetization prior to the ARM acquisition experiment. Each type of data is checked prior to proceeding to the next step. Over 5000 data points (depending on number of demagnetization steps) can be accumulated for a single u channel in ~10 h, while hundreds of u channel samples may need to be processed for one deep-sea drilling site. Checking and processing these data, displaying orthogonal projections [*Zijderveld*, 1967] for each measurement position, calculating or optimizing the component magnetization directions by principal component analysis (PCA) [*Kirschvink*, 1980], and estimating RPI are time consuming in the absence of software designed for these purposes. *Mazaud* [2005] developed Microsoft Excel software that incorporates microcommands to treat NRM data from long core sediment samples. The software requires introduction of data columns from the respective measurement data files to certain regions of the Excel file, and is capable of calculating component directions and median destructive fields, as well as drawing orthogonal projections for each measurement position.

[5] The new UPmag software described here contains three graphical user interfaces that are designed to view and process routinely measured u channel paleomagnetic data such as NRM, ARM and IRM data. The software allows the user to open and check through the measurement data, and corrects for flux jumps in the data if necessary. In addition to interactively calculating (optimizing) and displaying PCA values, orthogonal projections, and stepwise intensity data for any measurement position, UPmag also enables data visualization in virtual geomagnetic pole (VGP) maps and equal area projection plots. Using UPmag, RPI estimates can be evaluated and compared using two methods: the slope of the best fit line between NRM and normalizer demagnetization data [e.g., *Channell et al.*, 2002], and the average of NRM/normalizer ratios [e.g., *Channell et al.*, 1997].

2. Description of UPmag

[6] UPmag is developed in MATLAB$^{\text{TM}}$ (version R2008b) on a PC with a Windows XP operating system. UPmag consists of three MATLAB$^{\text{TM}}$ graphical user interfaces: UVIEW, UDIR, and UINT. Each interface facilitates certain aspects of processing u channel paleomagnetic data. UVIEW

displays the measurement data, corrects for flux jumps, and prepares data for further treatment. UDIR focuses on calculation and visualization of directional data such as calculated PCA and VGP. UINT calculates relative paleointensity estimates. These programs can be activated by typing "UVIEW," "UDIR," and "UINT" (all in capital letters) followed by a return key in the MATLAB^{TM} command window. The UPmag program folder should be under the MATLAB^{TM} current directory or should be added to the MATLAB^{TM} search path when running UPmag. The UPmag programs, data format files, and test data can be found at http://earthref.org/cgi-bin/er.cgi?s=erda.cgi?n=985. A typical flow path for processing u channel paleomagnetic data using UPmag is summarized in Figure 1.

2.1. UVIEW

[7] UVIEW reads NRM, ARM or IRM measurement files created by the u channel magnetometer measurement system. Contents of a typical measurement file generated at UF, by the LABVIEW^{TM} software accompanying the 2G Enterprises u channel magnetometer, are listed in Table 1. After selecting "Load Measurement File" from the "File" menu (Figure 2), UVIEW asks for the type of the data (e.g., NRM or ARM) and whether the data are in default UF format (Table 1). The data type is used later to label the exported files. A measurement file format table (i.e., "Measurement_File_Format.txt," which is also available for download) must be modified and loaded to UVIEW first, if the measurement file is not in the default format.

[8] After importing the measurement file, information about u channel samples and demagnetization procedures are automatically listed in the "File Information" panel (Figure 2a). Initially, the remanence intensity data for the respective orthogonal sample axes (Xint, Yint, and Zint; see Table 1) from the first demagnetization step of the first u channel sample are displayed (Figure 2a). The list of parameters available for plotting is grouped in the "Plot Parameters" panel. To view a parameter, choose the radio button associated with the parameter. As an example, Figure 2b contains plots of intensity (Int), declination (Decl), and inclination (Incl) data for the same demagnetization step for the same u channel shown in Figure 2a. The "Now Checking" panel hosts components that allow the user to check through data and plots (for a selected parameter) for different demagnetization steps and for different u channel samples. Multiple demag-

netization steps for a u channel sample can be plotted together (Figure 2c) by toggling the "View Multiple Steps of This Sample" button. The range of steps is adjustable using the two pop-up menus in the "Now Checking" panel.

[9] Occasionally, a flux jump may occur during the pass-through measurement, in which a sudden (abrupt) change in magnetization appears at a certain measurement position for a particular axis. Flux jumps are generally rare, random, and nonpredictable, and yet they greatly distort the data. Although remeasuring the sample would usually be ideal, remeasuring may often not be feasible if the flux jump was not immediately recognized. In UVIEW, if flux jumps are observed at any stage when scrolling through the measurement data, a correction can be initiated by clicking on "Correct Current Data" in the "Flux-Jump" panel. Flux jumps can be located either manually or automatically. A threshold value can be set for the automatic detection, and different interpolation methods are available for correcting flux jumps. After correction, a diagram comparing the measurement data before and after flux jump correction will be displayed (Figure 2d), and all data related to the flux jumps will be updated if the correction is accepted by the user. After checking and correcting for flux jumps for all u channel samples, a new "measurement" file can be generated using the "Save Corrected Data" button in the "Flux-Jump" panel.

[10] All plots displayed in UVIEW can be modified and exported in various formats such as jpg, bmp, pdf, or eps. For example, the user can zoom and pan the plots, add legends, titles, grids, or data value markers. The "Hold on/off" tool facilitates comparison of different data plots when toggled. The "Print" tool allows the user to save the whole figure, including plots and information listed in various panels, to a pdf file. UVIEW also exports two types of data file: *.dir and *.int. The two files truncate data from the leader and trailer (see Table 1), and regroup the measurement data by position in the u channel. The *.dir file features declination, inclination, and intensity data (typically from NRM data), reorganized by measurement position, for further direction-related investigation in UDIR. The *.int file reformats intensity data by measurement position for RPI estimation in UINT.

2.2. UDIR

[11] UDIR opens *.dir files generated by UVIEW or by other sources. The default UF-formatted *.dir file is represented in Table 2. If the *.dir file is not
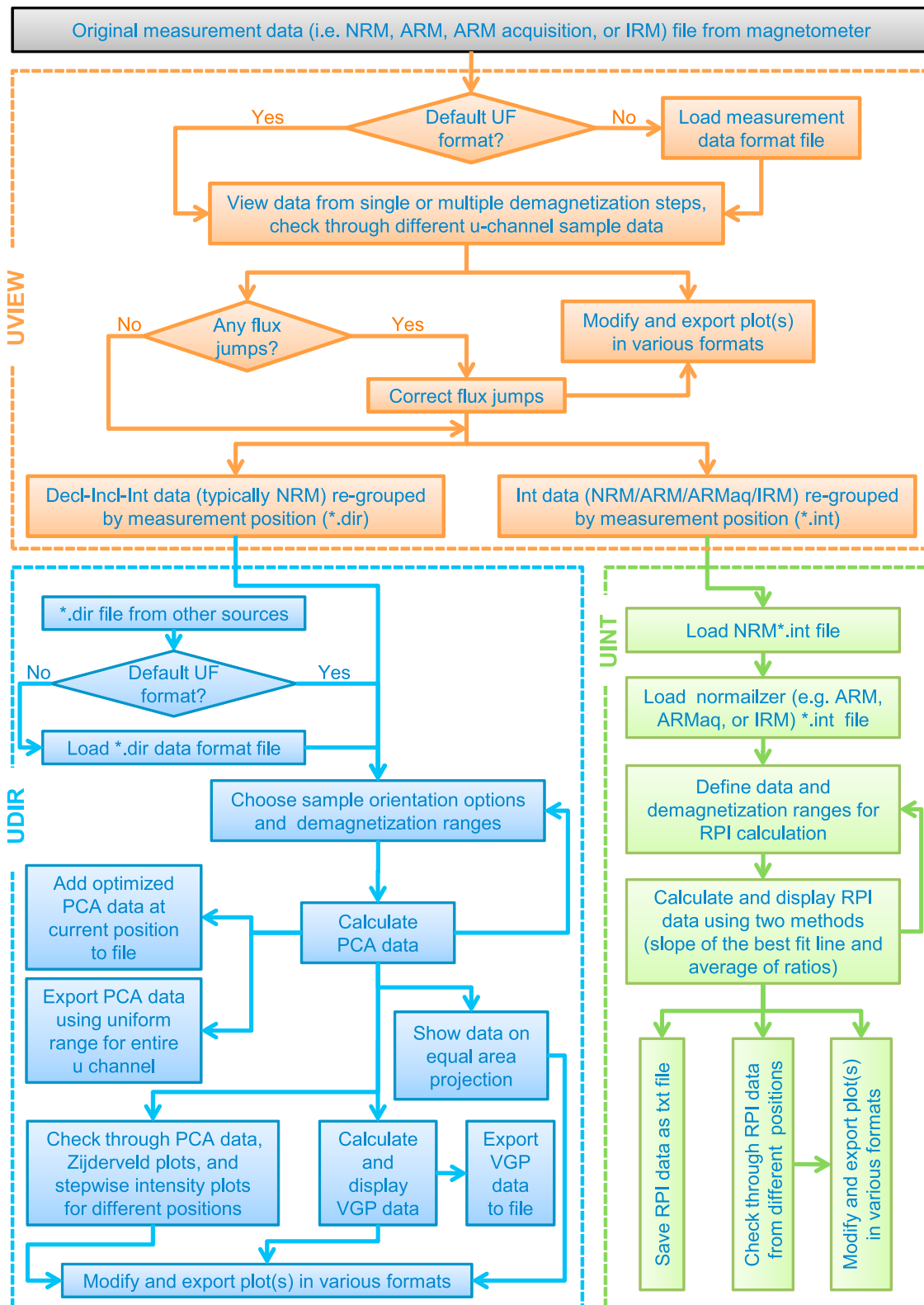
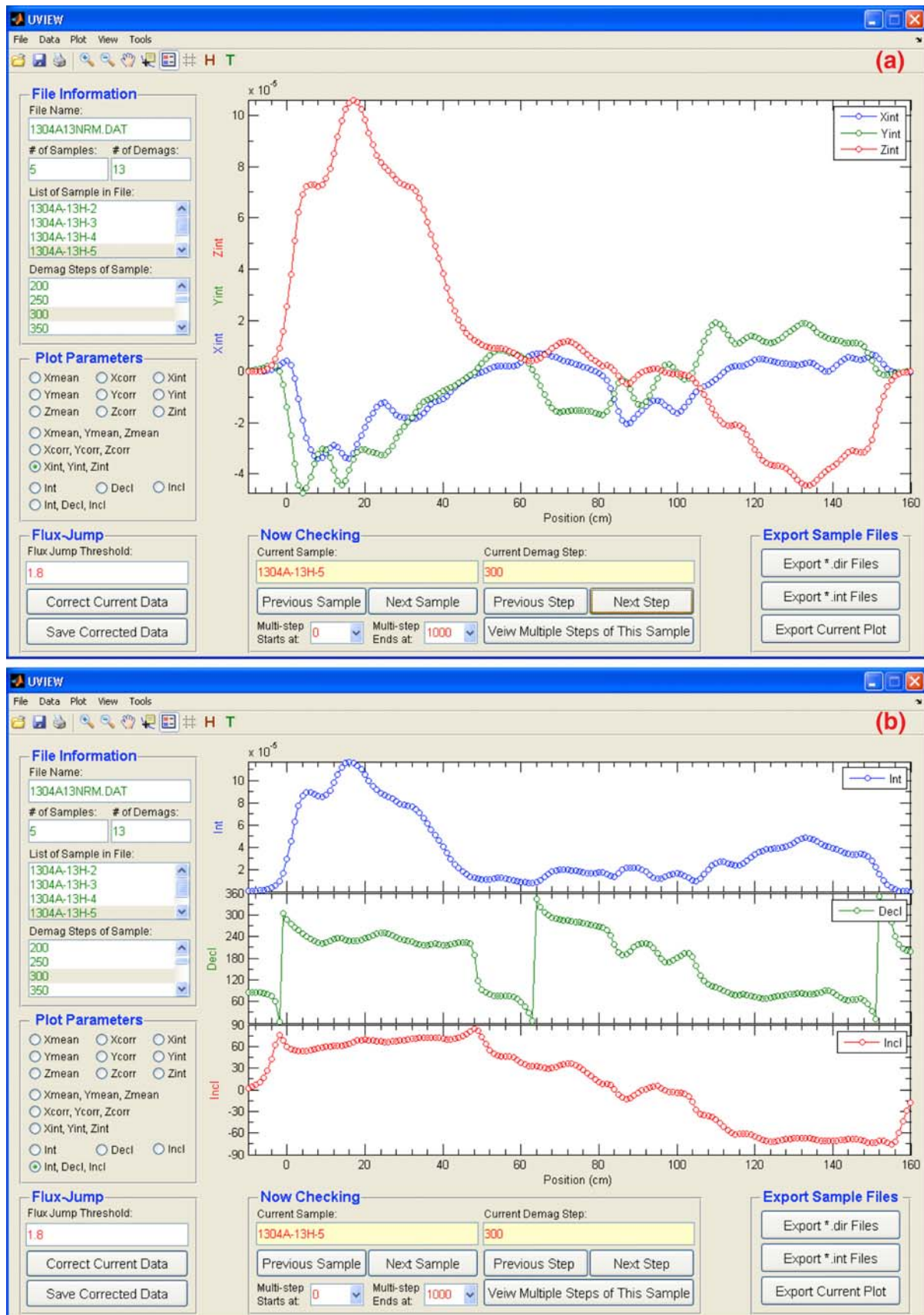**Figure 1.** A flowchart summarizing the logic and major steps of using the UPmag software.
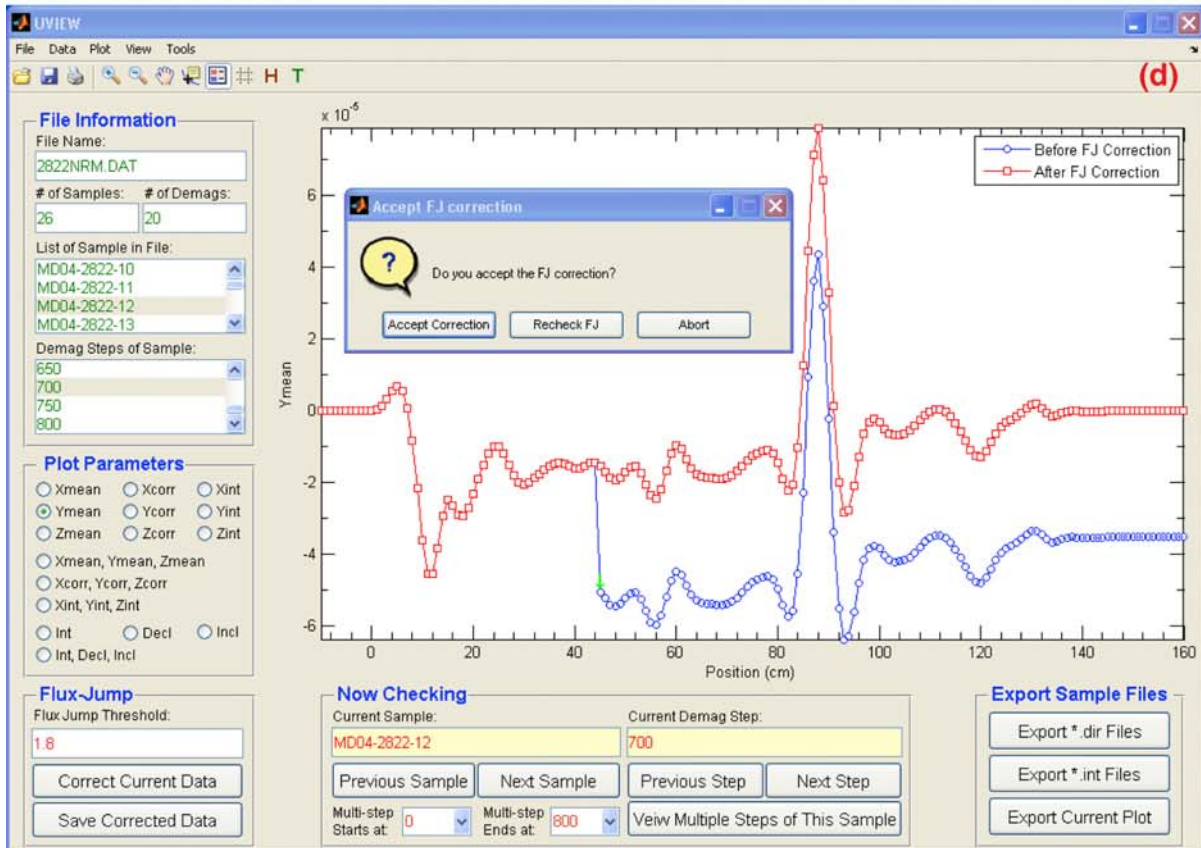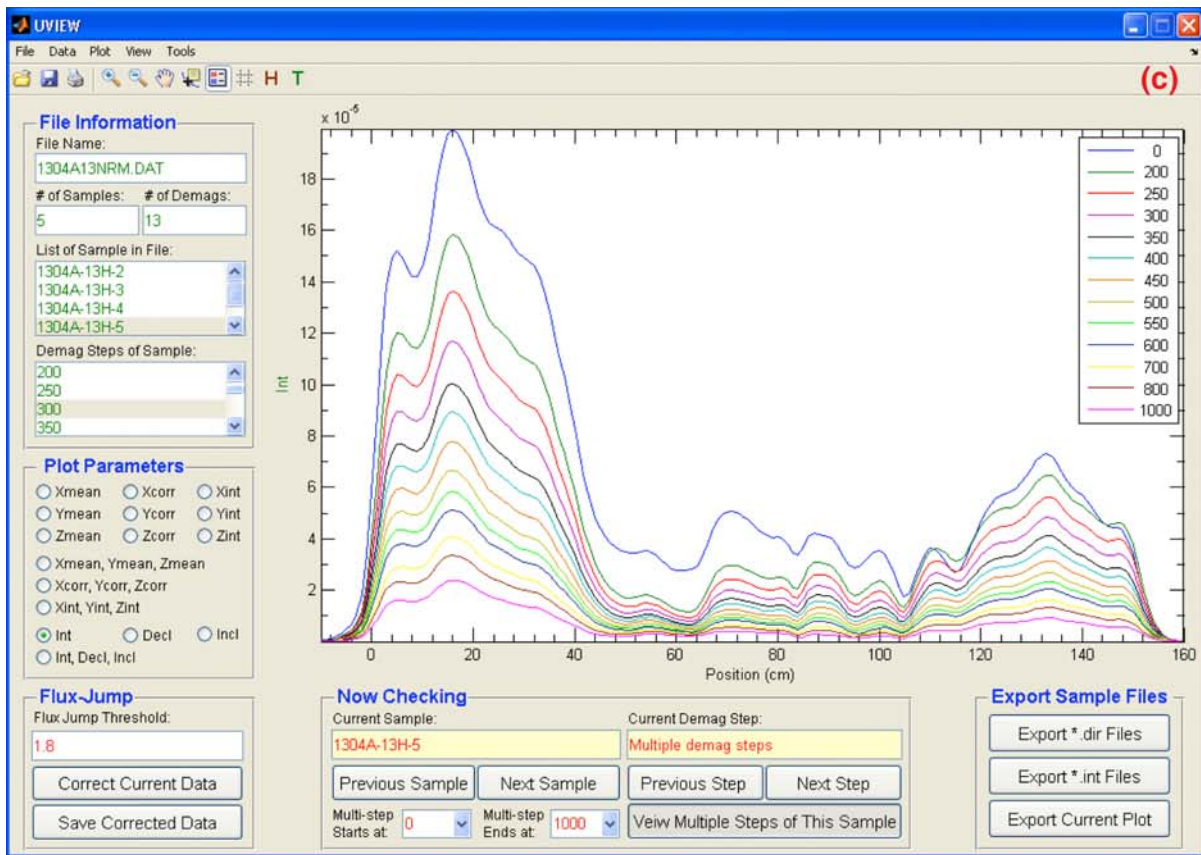
Figure 2

Figure 2. (continued)

Table 1. Default UF Measurement Data File Format[a]

Columns in Measurement Data File	Column	Format String	Explanation
Sample ID	1	%s	name of u channel sample
Position	2	%f	measurement position in u channel
Depth	3	%f	depth of the position in the sedimentary sequence
AF X[b]	4	%f	demagnetization peak field on X measurement axis
AF Y[b]	5	%f	demagnetization peak field on Y measurement axis
AF Z[b]	6	%f	demagnetization peak field on Z measurement axis
Declination: Unrotated	7	%f	declination from corrected X and Y intensity
Inclination: Unrotated	8	%f	inclination from corrected X, Y, and Z intensity
Intensity	9	%f	intensity from corrected X, Y, and Z intensity
X intensity	10	%f	X magnetic moment
X mean	11	%f	X volume magnetization
X corr	12	%f	X mean after drift and tray correction
Y intensity	13	%f	Y magnetic moment
Y mean	14	%f	Y volume magnetization
Y corr	15	%f	Y mean after drift and tray correction
Z intensity	16	%f	Z magnetic moment
Z mean	17	%f	Z volume magnetization
Z corr	18	%f	Z mean after drift and tray correction
ARM Gauss	19	%s	bias field used for generating ARM
ARM axis	20	%s	direction of the applied bias field
Orientation	21	%s	archive or working half of core
Leader length	22	%f	positions measured before 1st position of u channel
Trailer length	23	%f	positions measured after last position of u channel
Drift corrected	24	%s	whether drift correction applied
Tray corrected	25	%s	whether tray correction applied
Sample Timestamp	26	%s	time stamp for u channel measurement
Tray Timestamp	27	%s	time stamp for last tray measurement
Run number	28	%s	run (ID) number assigned to measurement

[a] Bold font indicates items that have to be included in a measurement data file; "%s" or "%f " indicates columns composed of strings or numbers, respectively. If measurement data file is not in the above default UF format, the "Measurement_File_Format.txt" file (available at http://earthref.org/cgi-bin/er.cgi?s=erda.cgi?n=985) must be modified accordingly and loaded to UVIEW prior to loading the measurement data file.
[b] Note that in the default UF format, after data reduction, X, Y, and Z measurement axes correspond to north, east, and vertical components, respectively.

in this format, the "Dir_File_Format.txt" file (available for download) must be modified accordingly and loaded to UDIR prior to loading the *.dir file. After successful loading of a *.dir file, component directions for the entire u channel are calculated using PCA [*Kirschvink*, 1980], with a default sample orientation option and demagnetization range. Component declination and inclination, and maximum angular deviation (MAD) values, determined from the PCA calculation, and intensity data (for a single demagnetization step) for the entire u channel are displayed at the top of the UDIR interface, with an orthogonal projection and a stepwise intensity plot for the first measurement position at the bottom of the display window (Figure 3a).

[12] The sample orientation and demagnetization range (including the option of anchoring the best fit through the origin of the plot) for PCA calculations can be changed from the "Coordinates" and the "PCA Values" panels (Figure 3a), respectively. Related data and plots will then be updated accordingly. Similarly, the range of demagnetization steps for plotting the demagnetization data (bottom left), can be controlled for each measurement position using the "Plot Range" panel. The demagnetization data for any position can be plotted in three styles: a north/up orthogonal projection (Figure 3a, bottom left) or west/up orthogonal projection (Figure 3d, bottom left), or in a 3-D vector plot (Figure 3b, bottom left). These styles can be switched using the "Plot

Figure 2. The UVIEW graphical user interface illustrating the major features of the software: (a) Xint, Yint, and Zint data for a selected u channel sample at a selected demagnetization step; (b) intensity (Int), declination (Decl), and inclination (Incl) data for the same u channel for a uniform demagnetization interval; (c) intensity (Int) data from multiple demagnetization steps for a selected u channel sample; and (d) Ymean data for a u channel sample for a certain demagnetization step before and after correction for a flux jump.
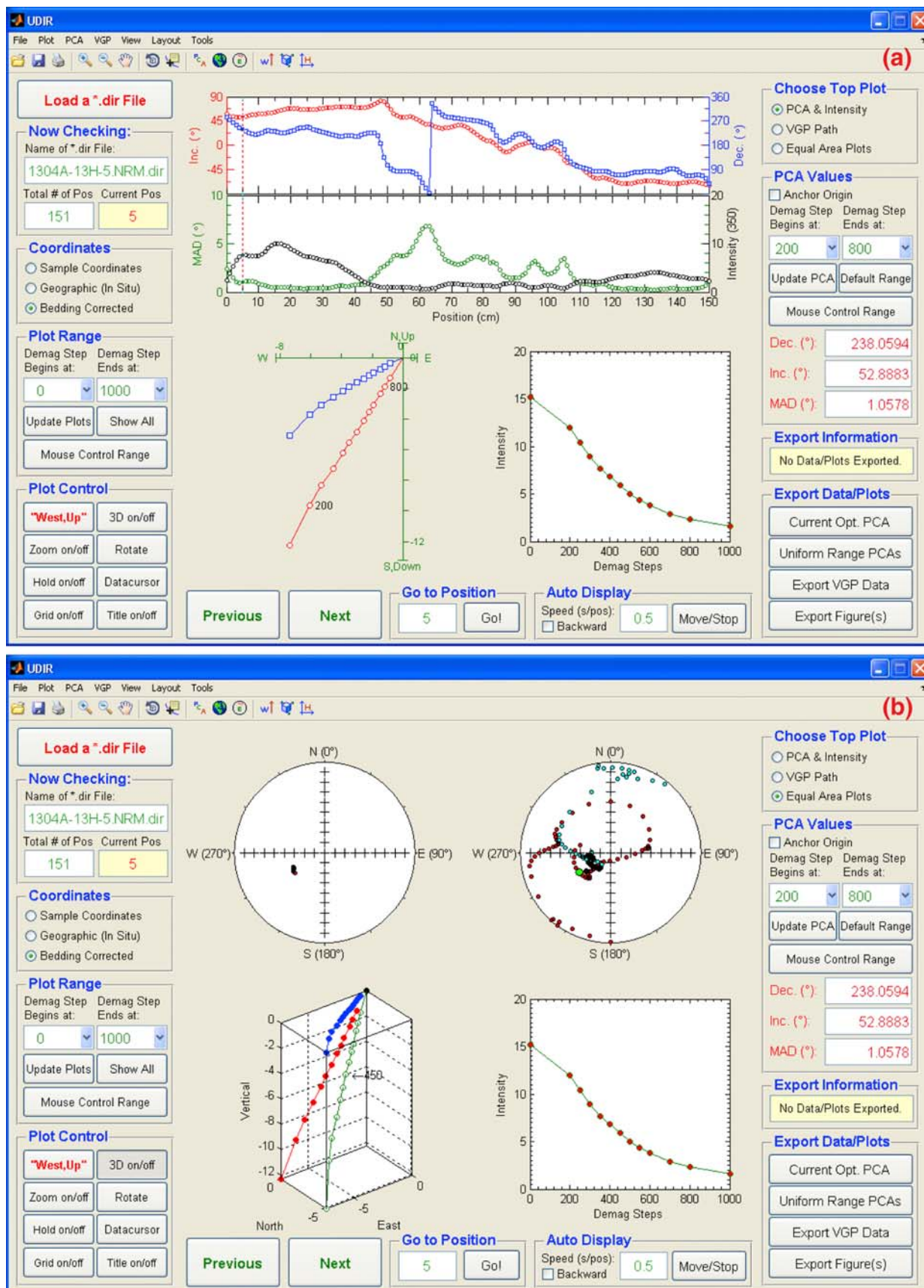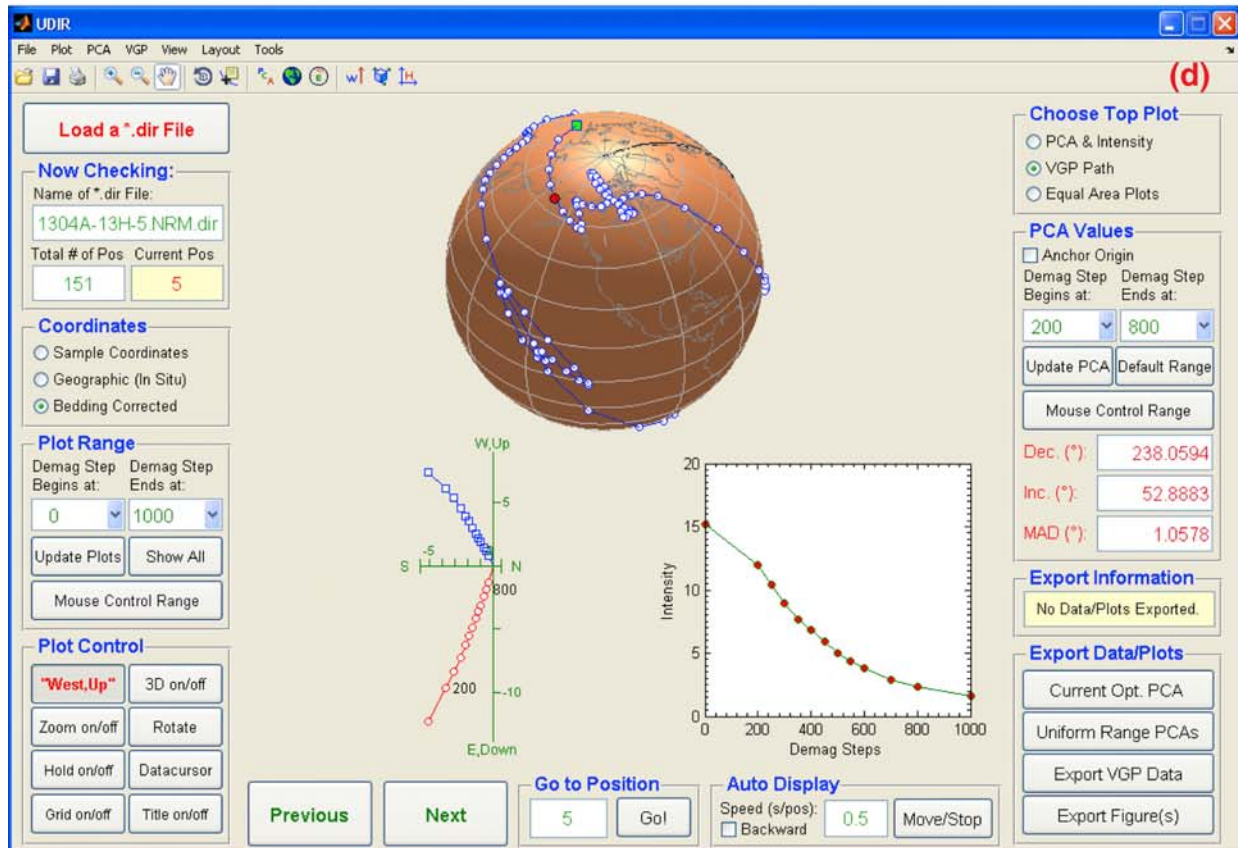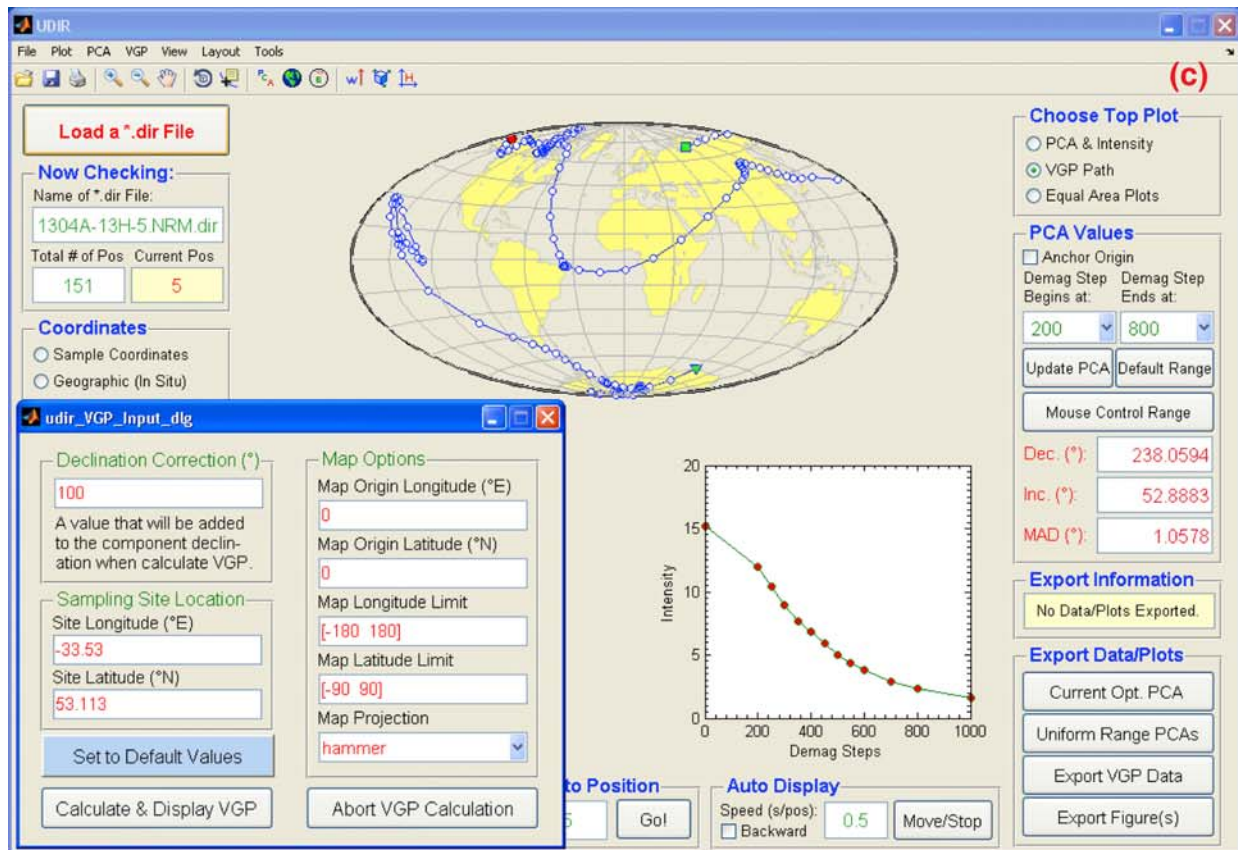
Figure 3

Figure 3. (continued)

Table 2. Default UF *.dir File Format[a]

Items in *.dir File	Column	Format String	Explanation
Position	1	%f	measurement position (usually in cm)
Treatment	2	%f	AF or thermal demagnetization level
IC	3	%s	instrumental code, e.g., "cryogenic"
CD	4	%f	circular standard deviation (for discrete sample)
Intensity	5	%f	measured intensity
DECL (Sample)	6	%f	declination in sample coordinates
INCL (Sample)	7	%f	inclination in sample coordinates
DECL (Geographic)	8	%f	declination in situ, no bedding correction
INCL (Geographic)	9	%f	inclination in situ, no bedding correction
DECL (Bedding)	10	%f	bedding corrected in situ declination
INCL (Bedding)	11	%f	bedding corrected in situ inclination
SUSC	12	%f	susceptibility
V/M	13	%f	volume or mass information

[a] Bold font indicates items that have to be included in a *.dir file; "%s" or "%f" indicates columns composed of strings or numbers, respectively. If the *.dir file is not in the above default UF format, the "Dir_File_Format.txt" file (available at http://earthref.org/cgi-bin/er.cgi?s=erda.cgi?n=985) must be modified accordingly and loaded to UDIR prior to loading the *.dir file.

Control" panel. The "Choose Top Plot" panel allows the user to switch the uppermost plots with the following options: intensity (for a single demagnetization step) and PCA data for all measurement positions (Figure 3a), demagnetization data for the selected measurement position and PCA data for all positions on an equal area stereographic projection (Figure 3b), and virtual geomagnetic pole (VGP) positions (which requires input of the sampling site location, declination correction if appropriate, and map projection, Figures 3c and 3d). The following options are available for scrolling through the data and plots from different measurement positions: (1) going to a specific position in the "Go to Position" panel by inputting the position and clicking on "Go!"; (2) manually controlling the position using the "Previous" and "Next" buttons; and (3) automatically displaying the data for each position at a user-defined speed by toggling the "Move/Stop" button in the "Auto Display" panel.

[13] Similar to UVIEW, all plots displayed in UDIR can be modified and exported in various formats. Component direction data and VGP data calculated using a uniform demagnetization range for the entire u channel can be exported by clicking on the "Uniform Range PCAs" and "Export VGP Data" buttons in the "Export Data/Plots" panel. It is sometimes convenient to optimize demagnetization ranges for PCA calculations at a particular measurement position, and then add the optimized PCA values to a txt file using the "Current Opt. PCA" button.

2.3. UINT

[14] UINT sequentially reads *.int files generated from NRM and laboratory-induced magnetization measurement data (e.g., ARM). The intensity data are displayed immediately to facilitate determination of the desired data range and demagnetization range for RPI calculation. Warning messages prevent selection of invalid data or demagnetization ranges.

[15] After clicking on the "Apply" button in the "Data Range Selection" panel, UINT updates the NRM and normalizer intensity plots with data in the selected range, calculates and displays RPI estimates using two methods: the slope of the best fit line and the average ratio between NRM and the

Figure 3. The UDIR graphical user interface illustrating the major features of the software: (a) orthogonal projection with north/up convention (bottom left) and stepwise intensity plot (bottom right) for the currently visualized measurement position, with intensity (at a single demagnetization step) and PCA data (declination, inclination, and MAD) for the entire u channel shown in the top two panels; (b) demagnetization data in 3-D (bottom left, in green: trajectory of the total vector; in red: projection of the vector endpoints on the vertical plane, and in blue: projection of the vector endpoints on the horizontal plane) and equal area projection (top left) with stepwise intensity data (bottom right) for the currently visualized measurement position, and PCA data for the entire u channel on an equal area projection (top right, in red: data with positive inclination; in cyan: data with negative inclination); (c) the same data as in Figure 3b with VGP data plotted on a "Hammer" projection (top), and input information window (bottom left) for VGP calculation; and (d) the same data as in Figure 3b with VGP data plotted on a 3-D "globe" projection, and demagnetization data shown on a west/up convention orthogonal projection.
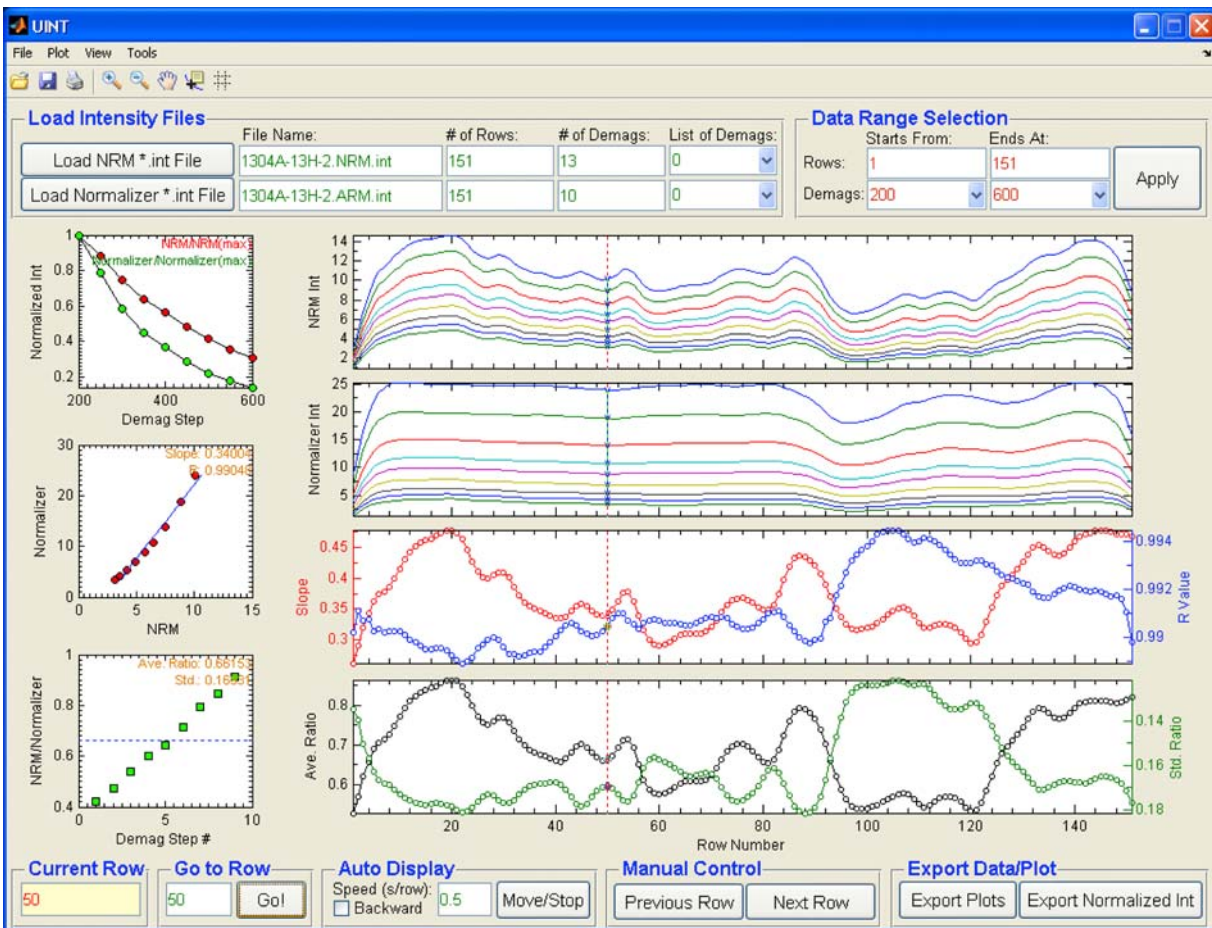
Figure 4. The UINT graphical user interface illustrating NRM and normalizer (ARM) intensity data from one u channel, RPI results estimated using slopes of the best fit line and average ratio (see text), and detailed information for the currently visualized measurement position in the u channel data files.

respective normalizer. The correlation coefficient (R) values for the best fit line, and standard deviations of the ratios, are also calculated (Figure 4). These values provide a measure of the quality/uncertainties of/in the RPI estimation. The respective intensity data within the selected range of demagnetization steps, the best fit line, and the ratios between the NRM and the respective normalizer are displayed on the left-hand side of the interface. The most appropriate normalizer activates the same grains that carry the NRM [e.g., *Levi and Banerjee*, 1976]. The top left-hand plot is a display of the coercivity spectra of the NRM and the normalizer, which aids in the choice of an appropriate normalizer for RPI estimation.

[16] Similar to UDIR, users can check through the data row by row of the two files manually or automatically. All plots presented in UINT can be modified and exported in various formats. RPI estimates calculated in UINT can be saved for

other operations. It should be noted that, although designed for RPI estimation, UINT can also be used to estimate grain-size proxies such as ARM/IRM, by simply loading ARM and IRM *.int files sequentially as the "NRM *.int File" and "Normalizer *.int File," respectively.

3. Conclusion

[17] UPmag aims to improve the efficiency of viewing and processing u channel or pass-through paleomagnetic data such as NRM, ARM and IRM data. The software consists of three graphical user interfaces called UVIEW, UDIR, and UINT. Each interface focuses on a specific aspect of treating u channel paleomagnetic data. UVIEW allows users to open and scroll through output data files from the u channel magnetometer measurement system as well as to correct for detected flux jumps in the data, and to export files for further treatment.

UDIR calculates, presents, and saves component direction data (i.e., declination, inclination, and MAD values) using the standard PCA method for either a uniform demagnetization range for the entire u channel or for an optimized range of demagnetization steps, anchored to the origin of the orthogonal projection or not. UDIR also calculates, displays, and saves VGP data, displays data on equal area projections, and conveniently scrolls through data for different measurement positions. UINT estimates, compares, and exports RPI data using the slopes of the best fit line or the averages of ratios between the NRM and a normalizer within a selectable range of demagnetization steps, with linear correlation coefficients (of slopes) and standard deviations (of ratios) calculated to monitor the quality of the respective RPI estimates.

Acknowledgments

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