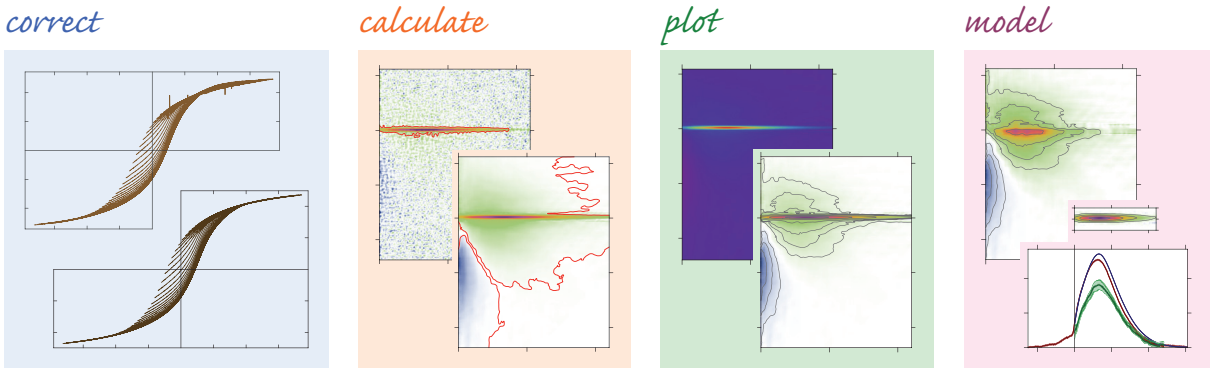
VARIFORC User Manual

Chapter 1:

Introduction



Obtain more from your FORC data

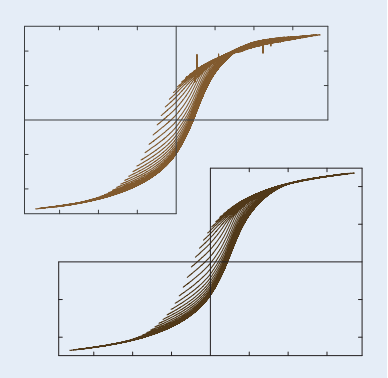
First-order reversal curve (FORC) measurements have been originally conceived by *Hejda and Zelinka* [1990] as a tool for obtaining a two-dimensional map of magnetization processes ideally represented by the superposition of elemental hysteresis contributions [*Preisach*, 1935]. Since then, FORC measurements have been used for detailed understanding of magnetization processes in the most various magnetic materials, and, more recently, for the characterization of geologic materials through their ferrimagnetic inclusions. Important information is often hidden in subtle details of FORC measurements, such as first derivative discontinuities, which require careful processing in order to be correctly identified. Therefore, optimal FORC processing procedures depend often on competing requirements in terms of detail preservation and measurement noise suppression.

VARIFORC is the first software package developed to comply with all standard and special processing requirements. It includes recent technical improvements of the original algorithm by *Pike et al.* [1999], such as weighted polynomial regression [*Harrison and Feinberg*, 2008], heteroscedastic error calculations [*Heslop and Roberts*, 2012], variable smoothing [*Egli*, 2013], as well as additional functionalities for coercivity analysis [partly from *Winklhofer and Zimanyi*, 2006] and central ridge processing [*Egli et al.*, 2010; *Egli*, 2013]. It is also the first software that provides quantitative FORC diagram analyses, such as coercivity distribution and central ridge extraction.

The VARIFORC package is a collection of modules that perform specific FORC processing operations. The first two modules for importing FORC measurements and calculating the FORC diagram are used in all cases. Further modules are available for generating publishing-quality FORC diagrams with added features such as contour lines, and for additional operations such as the linear combination of FORC data and central ridge processing. The package structure enables simplest entry-level processing with standard options, as well as more advanced operations for quantitative FORC analysis [*Egli et al.*, 2010; *Egli*, 2013; *Ludwig et al.*, 2013].

The VARIFORC package runs with Wolfram Mathematica® and Mathematica PlayerPro®. Previous knowledge of Mathematica is not required. Mathematica PlayerPro is recommended for users not interested in Mathematica applications, because of the reduced license costs (ca. 240 US$ or 190 € plus taxes). See Chapter 2 about installation for further details.

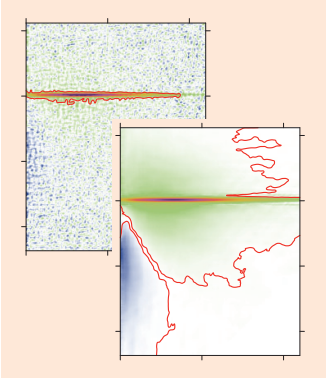
The following modules are presently available within the VARIFORC package:



ImportFORC

Import and correct FORC measurements

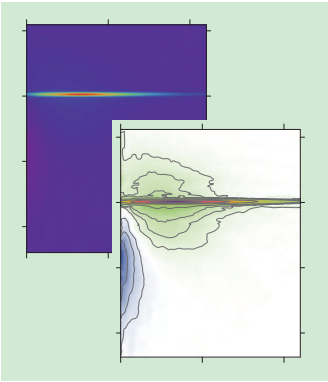
- Supports all known FORC data formats generated by MicroMag™ magnetometers.
- Correct measurement artefacts such as drift, transient instabilities, and outliers.
- Check and optionally corrects problems with first and last point measurements due to field sweep effects (older measurements).
- Manage field and magnetization units, and normalize measurements by mass, volume, and area. Correct units are essential for comparing FORC data with conventional magnetic measurements.
- Average multiple measurements of weak samples. Several fast measurements of a complete set of FORCs are better than a single measurement with long averaging time. Multiple measurement files obtained with the same measuring protocol are automatically combined into a single set of FORCs, with individual FORC measurements weighted according to their quality.
- Calculate hysteresis loop parameters with manual or automatic paramagnetic correction. It is always better to measure an independent hysteresis loop to higher fields – but if you do not have one, VARIFORC uses an approach-to-saturation method [*Fabian*, 2006] to obtain best possible estimates with available FORC data. High-field correction does not affect FORC diagram calculations; however, it enables much better measurement visualization, especially in case of very large high-field susceptibilities.
- Plot corrected and averaged FORC measurements with and without subtraction of the lower hysteresis branch from all curves. Details of the measured curves that are usually hidden within the (small) space enclosed by the hysteresis loop, such as first derivative discontinuities, become immediately evident in such plots.
- Export corrected FORC measurements and FORC measurements with subtracted lower hysteresis branch for further processing.



CalculateFORC

Calculate FORC diagrams

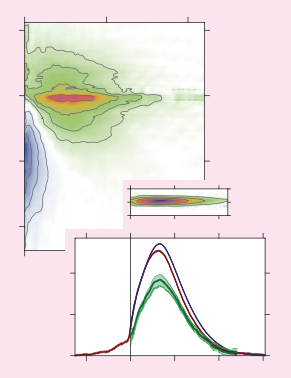
- Free choice of the FORC region to be calculated. Extended regions, including all FORC measurements beyond the standard rectangular space defined by the FORC protocol, are possible.
- Automatic or manual choice of the output grid on which the FORC function is computed.
- Weighted and unweighted polynomial regression over rectangular arrays of measurement points.
- Conventional FORC processing with constant smoothing factors.
- Advanced FORC processing based on variable smoothing for optimal noise suppression over different regions of the FORC diagram with given resolution requirements. Automatic adaptation of smoothing parameters to the main hysteresis characteristics.
- Optional processing of FORC measurements with subtracted lower hysteresis branch, especially designed to eliminate processing artifacts produced by features that are common to all magnetization curves (e.g. zero-coercivity contributions).
- Optional mean field correction or mean field simulation.
- Heteroscedastic error calculation and significance estimates.
- Automatic calculation of coercivity distributions derived from FORC data (i.e. first derivatives of the backfield demagnetization curve and of the irreversible magnetization component of the upper hysteresis branch).
- Automatic calculation of magnetizations derived from FORC data (e.g. saturation remanence and total irreversible magnetization of the upper hysteresis branch).
- Automatic plots of the FORC diagram and related errors with advanced color scales for optimal representation of high- and low amplitude details.
- Full control of all processing options for precisely reproducible outputs (e.g. identical output grids, regardless of measurement protocols and actually measured fields).
- Export FORC matrices and coercivity distributions with metadata for further processing with other VARIFORC modules and with third-party software.



PlotFORC

Publishing-quality FORC plotting

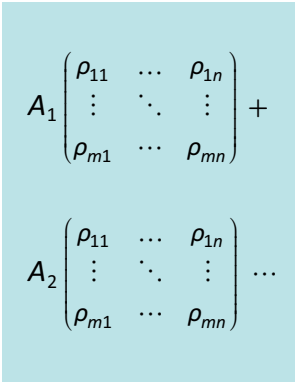
- Choose the FORC region to be plotted after seeing a preprocessed diagram. Zoom on details such as the central ridge region.
- Use advanced, adjustable color scales for optimal representation of high- and low amplitude details. The specially developed color scales are optimized for presentations and professional publishing. Manual saturation and contrast adjustments for meeting special requirements are possible.
- Draw contour lines automatically or manually at any specified level. Exclude small contour loops generated by measurement noise.
- Draw contours enclosing significant regions of the FORC diagram.
- Normalize vertical profiles in order to obtain direct estimates of the vertical width of the FORC function. This option is useful for estimating magnetostatic interaction field distributions and to derive quality parameters for absolute paleointensity determinations.
- Export high-quality FORC diagrams images with common vector and raster formats.



`IsolateCR`

Central ridge processing

- Isolate central ridges from the continuous background of other FORC contributions.
- Calculate the central ridge coercivity distribution and plot it together with the other two coercivity distributions derived from FORC diagrams.
- Decompose the bulk FORC function into its contributions from central ridge, background, and reversible SD processes. Plot these contributions separately with corresponding heteroscedastic error estimates.
- Calculate additional FORC-related magnetizations, such as the total contribution of the central ridge and of reversible SD processes.
- Export central ridge, background, and reversible SD FORC matrices, as well as the central ridge coercivity distribution, for further processing with VARIFORC modules (e.g. `PlotFORC`) or with other software.



`LinearCombineFORC`

Calculate linear combinations of FORC data

- Calculate any linear combination of an arbitrary number of FORC data sources.
- Average measurements obtained with different FORC protocols.
- Subtract a background contribution (e.g. sample holder).
- Isolate the contribution of specific minerals by calculating the difference between measurements performed before and after a certain treatment (e.g. selective dissolution of SD magnetite).

Learn by doing – documentation – tutorials

VARIFORC provides over sixty options for controlling various operations with FORC data. This might seem excessive, especially in comparison with common FORC diagram calculations based on a single parameter – the smoothing factor. Many VARIFORC options, however, are used for additional operations that are not available with standard processing software, such as editing (e.g. custom contour line drawing and color scales), and FORC range selection. Most critical options are related to the calculation of FORC diagrams with optimal smoothing parameters. In this case, default or automatic settings work fine in most cases. In order to facilitate both batch processing and advanced analyses – options can be stored is standardized files according to your own requirements and recalled automatically when needed. A library of option files used to process a variety of different materials is available online at the VARIFORC homepage.

You can quickly learn how to deal with VARIFORC options through the following steps:

1. ***Quick start***. Default start-up options are automatically available after installation of the VARIFORC package. You can use these options to obtain first results without experience.
2. ***Learn by doing***. A comprehensive set of typical examples is provided for download along with the VARIFORC package. Browse these examples to find one that is close to your application and copy its processing options.
3. ***Batch processing***. If you process FORC data obtained from similar samples with similar or identical FORC protocols (e.g. high-resolution measurements of sediment), prepare your own set of processing options and store it for later use. FORC processing from this point on becomes a fully automatized procedure.
4. ***Learn more about advanced FORC processing options***. This manual provides a complete description of VARIFORC modules, supported by over 100 illustrated examples. Use the quick reference guide to recall processing options once you have learned about them.
5. ***FORC tutorial***. This manual comes with a tutorial written by Ramon Egli and Michael Winklhofer on basic scientific knowledge about the fast evolving field of FORC analysis. Read this tutorial for planning effective FORC measurements that allow you to extract detailed information about magnetic processes occurring in your samples.

Support

VARIFORC has been extensively tested and its functionality is guaranteed with all examples available for download. Nevertheless, the occurrence of errors and processing problems can never be completely excluded for certain operations, such as central ridge isolation. In case of problems, or if you have suggestions for improving VARIFORC, contact the author (ramon.egli@zamg.ac.at). Personal assistance is offered if possible.

Literature

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