`RadialPlotter`: a Java application for fission track, luminescence and other radial plots

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September 3, 2008

Abstract

Single-grain measurements become common practice in fission track, ^{40}Ar / ^{39}Ar, U-Pb, (U-Th)/He and optical dating. Because single-grain signals are small, the measurement uncertainties of single-grain ages are typically larger and more variable than those of multi-grain aliquots of the same sample. Invented by Rex Galbraith in 1988, the radial plot is a graphical method for comparing several estimates having different precisions. Radial plots have been used in fission track and luminescence dating, but can be applied to other kinds of data as well. RadialPlotter is the first standalone computer program implementing all these applications. The program has a simple interface for three kinds of data: Fission Tracks, Luminescence and 'Other'. Its graphical output can be saved in bitmap (`.png`) and vector (`.pdf`) formats. Data points can be colour-coded to show a third variable such as chemical composition or a kinetic parameter. RadialPlotter was programmed in Java and is, therefore, platform-independent. It can be downloaded free of charge from `http://pvermees.andropov.org/radialplotter`.

1 Introduction

Radial Plots are bivariate (x_j, y_j) scatterplots where:

$$x_j = 1/\sigma(z_j), \quad y_j = (z_j - z_0)/\sigma(z_j), \qquad \text{for } 1 \leq j \leq n \qquad (1)$$

with z_j a transformation of some data and $\sigma(z_j)$ the corresponding measurement uncertainty. For example, if $z_j = \log(t_j)$ then $\sigma(z_j) = \sigma(t_j)/t_j$. z_0 is a convenient central value such as the weighted mean. The slope of a line connecting the origin (x=0,y=0) of a radial plot with a data point (x_j, y_j) equals z_j, and the horizontal distance along x-axis is a measure if its precision. Thus, the radial plot simultaneously visualises a measurement's value and precision. No other graphical method achieves this goal with the same elegance. This makes the radial plot the method of choice for visualising heteroscedastic data, i.e.

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Figure 1: RadialPlotter and some sample input files can be downloaded from
`http://pvermees.andropov.org/radialplotter`.

data with (large and) variable measurement uncertainties. Traditional applications in the Earth Sciences are fission track and luminescence dating, which are governed by Poisson processes (e.g., Galbraith, 1988, 1990; Galbraith et al., 1999). In principle, however, radial plots can be used for any kind of data.

RadialPlotter is a user-friendly application for generating radial plots. It has the following advantages over existing programs such as `Trackkey` or `Mac-Track`. (1) The program was developed solely for radial plots and does not perform other functions for data reduction or interpretation. Therefore, radial plot functions are not buried deep inside the menu structure and the interface is very straightforward. (2) RadialPlotter was written in Java (version 5) and is, therefore, perfectly platform independent. (3) In addition to fission track radial plots, RadialPlotter also offers the possibility to generate radial plots for luminescence dating, or any other kind of data such as (U-Th)/He or U-Pb ages. Hopefully, this will give the radial plot the wider user base which it deserves.

Section 2 explains RadialPlotter's straightforward installation procedure. As explained before, radial plots generally apply some kind of transformation to the data before plotting. Different transformations apply to different kinds of data. Section 3 discusses the three different input formats (fission tracks, luminescence, and 'other') and the data transformations applicable to them. Being a plotting application, RadialPlotter produces graphical output, which can be saved in various image formats. Section 4 discusses how to set the colours and scale of a radial plot to generate publication-ready results.

2   Installation

RadialPlotter can be downloaded free of charge from `http://pvermees.andropov.org/radialplotter` (Figure 1). The program consists of a single executable jar file (`RadialPlotter.jar`). This makes installation of the program straightforward: it suffices to download and open this file to run RadialPlotter. The program requires Java Runtime Environment (JRE) 5 or higher (the current version is 6), which is pre-installed on most computers. The latest JRE

version can be downloaded free of charge from `http://www.java.com/down-load`. For MS Windows users, an executable wrapper (`RadialPlotter.exe`) is available from the RadialPlotter website. This program automatically checks the JRE version of the computer and redirects the user to the JRE download site if necessary.

For testing purposes, three example input files are provided on the website, one for each of the three input formats implemented in RadialPlotter: `FT-data.csv` (fission tracks), `OSLdata.csv` (luminescence) and `OTHERdata.csv` (U-Th-He ages). The next section explains these input formats in more detail.

3   Three input options

Data can be copied and pasted to-and-from Microsoft Excel with RadialPlotter's `Edit` menu or by the usual `Ctrl-C` and `Ctrl-V` shortcuts. Simple editing tools for inserting and deleting rows are available as well. Clicking `File → Save Data` saves the data in a comma-separated-variable (`.csv`) format. Therefore, input files can also be edited by hand in a spreadsheet or word-processor. Clicking `Options → Input` brings up a menu to toggle between the three input formats: `Fission Tracks`, `Luminescence` and `Other`. The following sections provide more details about these options.

3.1   Fission Tracks

```
samplename [,flag]
zeta       [,zeta-err]
rhoD       [,rhoD-err]
Ns(1)       ,Ni(1)     [,C(1)]
Ns(2)       ,Ni(2)     [,C(1)]
...         ...         ...
Ns(n)       ,Ni(n)     [,C(n)]
```

The input file begins with a mandatory sample name (or a blank line), followed by an optional flag. If the flag equals 'F', the `Fission Tracks` option box in the `Options → Input` menu user is automatically selected. If not, then the user must make sure to check that the correct option is set.

RadialPlotter's `Fission Tracks` setting implements the external detector method (Hurford and Green, 1983). The second line of the input file is the ζ (`zeta`) calibration constant and its (optional) standard error, both in cm yr^2. To generate radial plots for ICP-MS-based fission track data (Hasebe et al., 2004), calculate the single-grain ages and use them as input to the `Other` option (Section 3.3).

`rhoD` is the fission track density of a Uranium standard glass detector that was irradiated along with the sample, and its (optional) standard error, in cm^{-2}.

The remainder of the input file contains `n` rows of fission track data: `Ns` = the number of spontaneous tracks (N_s), `Ni` = the number of induced fission

tracks in the mica external detector (N_i), `C` = an optional parameter to be used for the colour code. This column can be used to show kinetic parameters such as Dpar (Donelick et al., 1999) or chlorine-content (Green et al., 1989). If `C` is omitted, the fill colour of the data points will be white.

As explained in Section 1, rather than working with the raw data, radial plots generally employ some kind of mathematical transformation. In the case of fission track dating with the external detector method, Galbraith (1990) proposed three transformations, which are available in the `Options` $\rightarrow$ `Transformations` menu:

`Linear:`

$$z_j = \frac{1}{\lambda} log\left(1 + g\zeta\lambda\rho_D \frac{N_s(j)}{N_i(j)}\right) \tag{2}$$

$$\sigma(z_j) = z_j\sqrt{\frac{1}{N_s(j)} + \frac{1}{N_i(j)}} \tag{3}$$

$$z_0 = \frac{\sum_{j=1}^{n} z_j/\sigma(z_j)^2}{\sum_{j=1}^{n} 1/\sigma(z_j)^2} \tag{4}$$

`Logarithmic:`

$$z_j = log\left(g\zeta\lambda\rho_D \frac{N_s(j)}{N_i(j)}\right) \tag{5}$$

$$\sigma(z_j) = \sqrt{\frac{1}{N_s(j)} + \frac{1}{N_i(j)}} \tag{6}$$

$$z_0 = log\left(g\zeta\lambda\rho_D \frac{\sum_{j=1}^{n} N_s(j)}{\sum_{j=1}^{n} N_i(j)}\right) \tag{7}$$

`Arcsine:`

$$z_j = arcsin\left(\sqrt{\frac{N_s(j) + \frac{3}{8}}{N_s(j) + N_i(j) + \frac{3}{4}}}\right) \tag{8}$$

$$\sigma(z_j) = \frac{1}{2\sqrt{N_s(j) + N_i(j)}} \tag{9}$$

$$z_0 = arcsin\left(\sqrt{\frac{\sum_{j=1}^{n} N_s(j)}{\sum_{j=1}^{n} N_s(j) + N_i(j)}}\right) \tag{10}$$

With λ the ^{238}U decay constant (=1.55125$\times 10^{-10}$a^{-1}), g a geometric factor (=0.5), and all other parameters as defined before. The `Logarithmic` transformation is used by default, unless there are grains with zero spontaneous tracks, in which case RadialPlotter defaults to `Arcsine`.

3.2 Luminescence

```
samplename [,flag]
doserate    [,doserate-err]
dose(1)      ,dose-err(1)   [,C(1)]
dose(2)      ,dose-err(2)   [,C(1)]
...           ...            ...
dose(n)      ,dose-err(n)   [,C(n)]
```

As before, the input file begins with the sample name, followed by an optional flag which, for luminescence dating, should be 'L'.

`doserate` is the estimated effective rate ($\dot{d}$) of ionizing radiation supplied to the sample by radioactive decay and cosmic rays, in units of Gray per year. `doserate-err` is the (optional) corresponding measurement uncertainty ($\sigma(\dot{d})$), also in Gy/yr.

The subsequent `n` rows contain the measured dose (d) and its standard error ($\sigma(d)$), both in Gy, plus an optional third column `C` which can be used as a colour code.

For luminescence dating, only two transformations are available:

`Linear:`

$$z_j \;=\; d_j/\dot{d} \tag{11}$$

$$\sigma(z_j) \;=\; z_j \frac{\sigma(d_j)}{d_j} \tag{12}$$

$$z_0 \;=\; \frac{\sum_{j=1}^{n} z_j/\sigma(z_j)^2}{\sum_{j=1}^{n} 1/\sigma(z_j)^2} \tag{13}$$

`Logarithmic:`

$$z_j \;=\; log(d_j/\dot{d}) \tag{14}$$

$$\sigma(z_j) \;=\; \frac{\sigma(d_j)}{d_j} \tag{15}$$

$$z_0 \;=\; \frac{\sum_{j=1}^{n} z_j/\sigma(z_j)^2}{\sum_{j=1}^{n} 1/\sigma(z_j)^2} \tag{16}$$

RadialPlotter defaults to `Logarithmic`. To use the `Linear` option, click `Options` → `Transformation` → `Linear`.

3.3 Other

```
samplename [,flag]
x(1)       ,x-err(1)   [,C(1)]
x(2)       ,x-err(2)   [,C(1)]
...         ...         ...
x(n)       ,x-err(n)   [,C(n)]
```
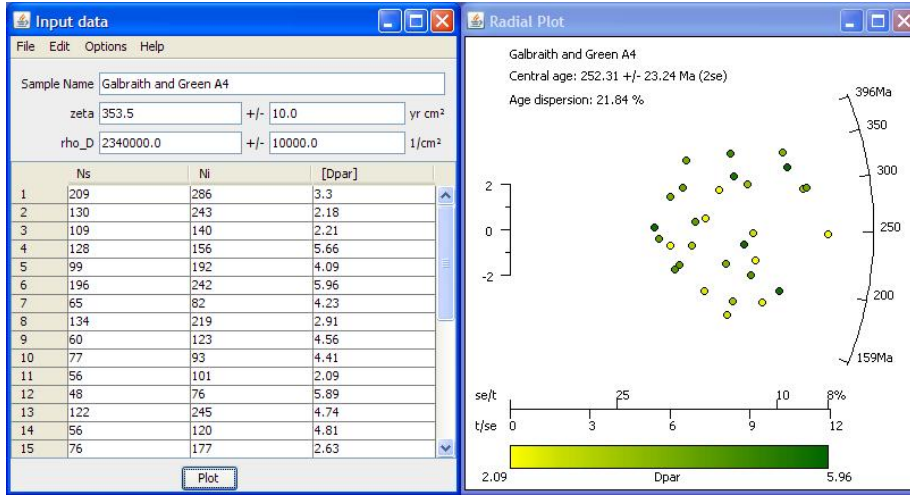
Figure 2: Input (left) and output (right) in the case of fission track dating.

In addition to fission track and luminescence ages, any kind of other data can be shown on radial plots as well. The input file of these 'other' data consists of a line with the sample name and an optional flag ('O' for Other) followed by n lines of data (x), analytical uncertainties ($\sigma(x)$), and an optional colour code. Again, two transformations are available, with a default set to Logarithmic.

Linear:

$$z_j = x_j \tag{17}$$

$$\sigma(z_j) = \sigma(x_j) \tag{18}$$

$$z_0 = \frac{\sum_{j=1}^{n} z_j / \sigma(z_j)^2}{\sum_{j=1}^{n} 1/\sigma(z_j)^2} \tag{19}$$

Logarithmic:

$$z_j = log(x_j) \tag{20}$$

$$\sigma(z_j) = \frac{\sigma(x_j)}{x_j} \tag{21}$$

$$z_0 = \frac{\sum_{j=1}^{n} z_j / \sigma(z_j)^2}{\sum_{j=1}^{n} 1/\sigma(z_j)^2} \tag{22}$$

4 Output

After clicking the Plot button, a new window appears containing the radial plot, a data summary and, if three columns of data were provided, a colour

scale (Figure 2). These components can be customized in various ways, through actions in the `Options` menu.

4.1 Adjusting the scale, labels and colours

RadialPlotter uses a circular scale. The default values for the minimum, maximum and central values (z_0) can be changed in the `Options` → `Scale & Labels` menu. Using a common radial scale for different samples facilitates their intercomparison. The `Scale & Labels` menu also contains a checkbox for adding labels to the data points, providing an interpretive link between the data table and radial plot. Single-grain ages and their uncertainties can be determined by clicking anywhere on the radial plot window. Pressing the `Ctrl`-button while clicking adjusts the horizontal scale.

The upper left corner of the output window shows a data summary. For fission tracks and luminescence dating, the central age and age dispersion are given. This is an arguable better estimator of central tendency than the arithmetic mean, because it takes into account the lognormal nature of N_s/N_i (in Equation 4), and of $d/\dot{d}$ (in Equation 16). However, the arithmetic weighted mean is still used for the `Other` option.

The colour bar consists of 100 steps, calculated by linear interpolation between the minimum and maximum values of the third data column. The minimum and maximum colour can be set by opening the `Options` → `Colours` menu.

4.2 Saving the output

RadialPlotter is capable of saving the graphical output as either bitmap or vector images, in a `.png` or `.pdf` format, respectively.

The `.png` (Portable Network Graphics) format employs a lossless data compression algorithm. Using imaging software such as Microsoft Paint, Adobe Photoshop, or the Gimp, this can be easily converted to similar formats such as `.gif`, `.jpg` or `.bmp`. The image resolution of the radial plot depends on the size of the output window. Therefore, for high quality image quality, it is recommended to maximise this window.

Alternatively, the `.pdf` (Portable Document Format) option saves the output in a vector format, which can be rescaled without loss of resolution. If saved in this format, the output can be edited in vector graphics software such as Adobe Illustrator or CorelDraw, and converted to formats like `.eps`, `.ai` or `.svg`.

5 Acknowledgments

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