CHRONOscope: APPLICATION FOR THE INTERACTIVE VISUALIZATION OF CARBON-14 AND BERYLLIUM-10 ATMOSPHERIC DATA

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ABSTRACT. Information about the global climate, the carbon cycle, changes in solar activity, and a number of other atmospheric processes are preserved in the carbon-14 and the beryllium-10 records. However, these isotope datasets are large and cumbersome to work with. We have designed a self-contained, easy-to-use application that allows for more efficient analysis of different periods and patterns of interest. For several applications in atmospheric modelling, a pre-processing stage is applied to the isotope datasets in order to interpolate the data and mitigate their low temporal resolution. In CHRONOscope, we included linear and non-linear methods of interpolation with interactive parameter optimization. The resultant interpolated data can be extracted for further use. The main functionalities of CHRONOscope include the importation and superimposition of external data, quick navigation through the data with the use of markers, expression of the carbon-14 results in both $\Delta^{14}C$ and yr BP form, separation of the data by source, and the visualization of associated error bars. We make this free software available in standalone applications for both Windows and Mac operating systems.

KEYWORDS: carbon-14, beryllium-10, data visualization, data interpolation.

INTRODUCTION

Measurements of carbon-14 (^{14}C, or radiocarbon) are primarily made for the age estimation of archaeological objects, such as wood, bones and shells. Currently, the most comprehensive dataset of atmospheric ^{14}C measurements is the IntCal13 Reimer et al. (2013) which comprises measurements of carbon-14 in known-age tree-rings over the Holocene and varved lake sediments during earlier periods. This dataset underpins the calibration of radiocarbon dates on materials of unknown age. However, using these data, researchers also investigate several solar processes, such as the periodicity of solar activity, Miyake Events, and atmospheric responses to environmental events. Another cosmogenic isotope that is used for similar tasks is beryllium-10 (^{10}Be), which is preserved in polar and high-altitude ice-cores.

Graphical interfaces are useful tools for several tasks such as data visualization and processing. In the literature, one can find interesting applications in environmental science for modelling, prediction, visualization and analysis of different data (Finkel and Nishiizumi (1997); Horiuchi et al. (2008); Berggren et al. (2009); Delaygue and Bard (2011); Heikkilä and Smith (2012); Pedro et al. (2012); Hu et al. (2015); Arundel et al. (2016); Rolph et al. (2017); Hossard et al. (2017); Arvesen et al. (2018)).

In this paper, we present an interface for visualization of the atmospheric IntCal13 dataset, for both the raw (individual laboratory) and modelled (consensus) data, and functions for processing and analyzing such as linear and non-linear data interpolation. In addition, we

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include ^{10}Be data, obtained from two key ice-core records, the NGRIP core in Greenland (Berggren et al. (2009)) and Dome Fuji, Antarctica (Horiuchi et al. (2008)). This software is available on the website of our ERC research project[1].

SOFTWARE AVAILABILITY

Name of software: CHRONOscope
 Developer: Andreas Neocleous
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 Email: neocleous.andreas@gmail.com
 Link: https://www.rug.nl/research/esrig/echoes/chronoscope
 Program Language: MATLAB
 Year first official release: 2018
 License: Free for non-commercial use.

SOFTWARE FUNCTIONALITY

Overview

The proposed software illustrates atmospheric data from available datasets and allows for interactive and detailed visualization of radiocarbon (^{14}C), Delta carbon-14 (Δ^{14}C) and beryllium-10 (^{10}Be). Navigation between different dates is easily achieved with the use of markers or by manual set-up of desired dates. A function for linear and nonlinear interpolation of the data is embedded and the new data can be exported in Microsoft Excel format. Finally, external data can be imported and superimposed on the existing ones.

Figure Tools

At the top of the application we introduce a number of plot tools that are the default for MATLAB figures. Using these, one can save the whole graph as a figure, zoom in or out, manually move the plot right or left, view particular data points and annotate data points.

Navigation

In the "navigation" panel, there are three edit boxes and two pushbuttons below every edit box. In the first two edit boxes, the user can set the date limits of the x-axis, and in the pushbuttons below, the user can select either Before Common Era (BCE) or Common Era (CE). In the third edit box, the user can add a locator (shown as a red vertical line in Figure 1). Below the pushbuttons, there is a radiobutton that centers the plot around the locator. The range of years that are encompassed is a parameter (default = 100 years) that can be set in the edit box next to the radiobutton. Finally, the "refresh" button will bring the figure back to the initial range.

Data Types

On the top right side of the application, we introduce five radiobuttons. The user can use these to navigate between the three data types: ^{14}C (yr BP), Δ^{14}C (‰) and ^{10}Be ($X10^3$ atoms/g or $X10^4$ atoms/g or $X10^5$ atoms/cm^2/year (flux)). The "link" radiobutton

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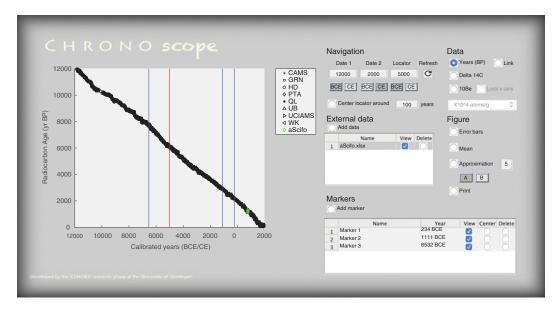[1]https://www.rug.nl/research/esrig/echoes/chronoscope

Figure 1   Software interface.

will plot the two data types of ^{14}C and $\Delta^{14}C$ in a subplot. The legend of the ^{10}Be, is interactive. All the data types that are illustrated can be selected or de-selected with a mouse click on their name in the legend. The ones that are de-selected are not shown in the figure. The x-axis can stay at its current limits by choosing the "Lock x-axis" radiobutton on the right. If this button is de-selected, the axis will be rescaled to the new range of the data that are plotted.

Data Processing and Visualization

The radiocarbon data typically have a 1 σ uncertainty expressed around each value (y-axis). The sample frequency (x-axis) is usually between 5 and 10 years, and on some occasions interpolation is needed. Another particularity of these datasets is that for the same years there are sometimes multiple values. This is because measurements are done by several laboratories that use trees from different parts of the world.

In CHRONOscope, in the "Figure" panel, one can visualize the uncertainty in the data by setting the "Error bars" radiobutton to "true" mode. In the same panel, we introduce the functions "Mean" and "Approximation". The functions interpolate the data linearly and non-linearly, respectively. One example of how the error bars and the approximations are shown in the application is illustrated in Figure 2. We call the linear interpolation "Mean" because before the interpolation, we compute an average between the highest and the lowest error values of the respective highest and the lowest data points, where multiple values occur. In the "Approximation" function we apply the "spline" non-linear interpolation method Reinsch (1967). We provide the option for the user to set some interpolation parameters manually, such as the number of breaks (resolution) that are used by the spline, and which data points are to be considered by the method. In the "Figure" panel below the "Approximation", we provide two options for the number of data points to be approximated. In option "A" we consider the entire dataset, while in option "B" we consider only the ones that are shown in the plot.

Table 1 Example on how the data should be ordered in the Microsoft Excel file for importing them to the CHRONOscope. These data have been acquired in the Center for Isotope Research at the University of Groningen.

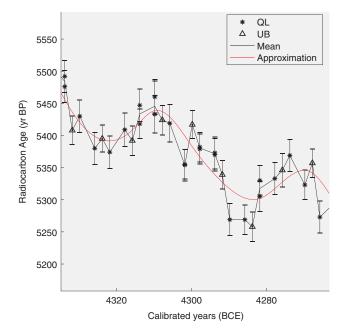| (x-axis) Age CE	(y-axis) Age (^{14}C years BP)	error + Age plus	error - Age min
771	1311.5	15	15
772	1295.2	15	15
773	1315.4	15	15
774	1282.9	15	15
775	1203.4	15	15
776	1127.3	15	15
777	1163.4	15	15
778	1172.0	15	15
779	1172.2	15	15

Figure 2   Example of how the error bars and the approximations are shown in the interface.

In this panel there is an option to print the current plot in an external figure and to save the plot in any available MATLAB graphics format.

External Data

In the "External data" panel, the user can import other data of their own. These data have to be in Microsoft Excel format and are uploaded from the menu (File / Import / Data). The data in the Microsoft Excel file should have the form described in the example shown in Table 1.

The data here have been acquired by the Center for Isotope Research in the University of Groningen, Scifo (2017).

A list of external data is shown in the same panel, where the user has the option to superimpose them on IntCal13 or to remove them entirely.

The data that are shown in the figure, including the interpolations, can be exported using File / Export / Data. They will be saved in Microsoft Excel format.

Markers

In the "Markers" panel, one can add markers for quick navigation between data of interest. The markers are shown in the Figure panel as vertical blue lines. A list of markers is shown in the same panel and the user can navigate between them by choosing the respective buttons on this list. The list of markers can be exported using File / Export / Markers.

CONCLUSIONS

CHRONOscope is a useful tool for the visualization and processing of atmospheric ^{14}C, $\Delta^{14}C$ and ^{10}Be data and it can be used in a wide range of analyses.

ACKNOWLEDGMENTS

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