ChronoModel

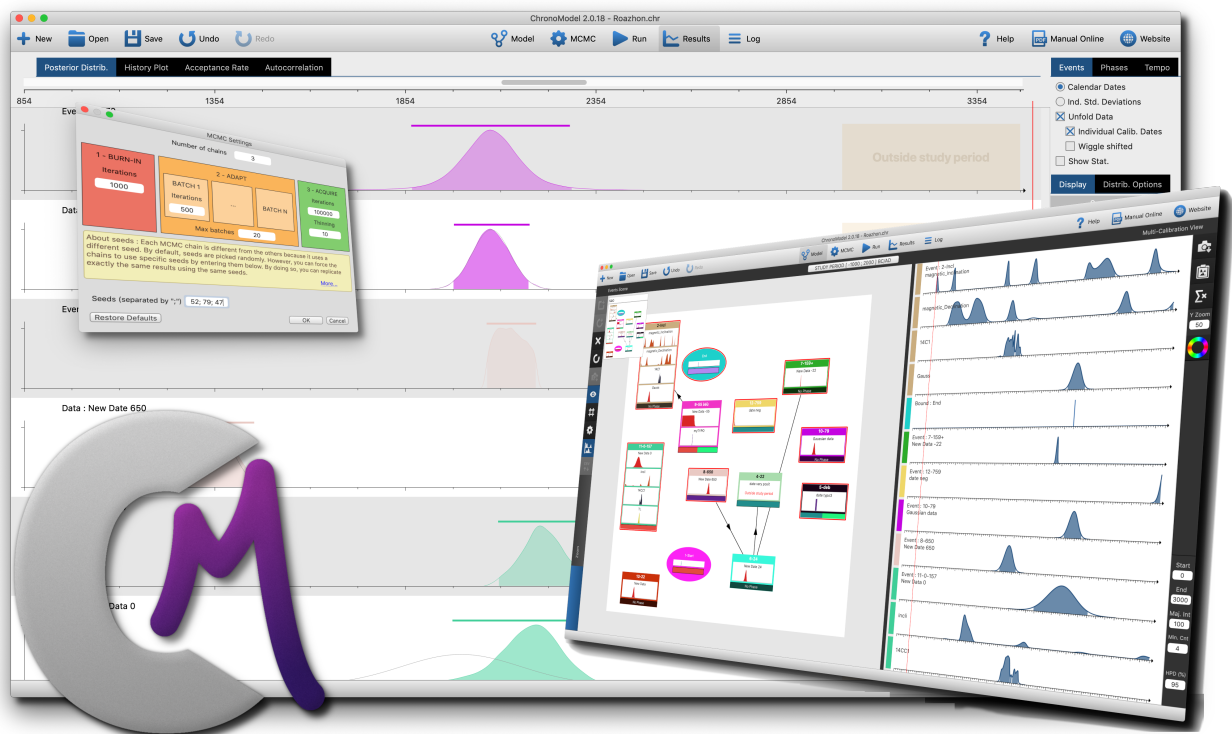## *version 2.0*

User manual

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Contents

1   Welcome to ChronoModel

ChronoModel (CM) is a user-friendly Bayesian chronological modeling tool for interpreting dating data along with expert chronological information. The software is freeware, open source and cross-platform (Mac, Windows, Linux). It presents a user-friendly interface where the data are handled using intuitive graphical elements (thumbnails). These elements explicitly show the data and all the prior information introduced in the model. Bayesian statistical models and methods implemented in CM are documented in peer-reviewed literature: see Lanos and Philippe (2017, 2018).

The present user manual provides a detailed description of how to use CM version 2.0. This version has been developed since April 2016 from the previous version 1.5 of ChronoModel: see Lanos et al. (2016); Vibet et al. (2016)

CM 2.0 can be freely downloaded from the web site https://chronomodel.com/download-chronomodel-software-mac-windows. The pre-compiled binaries of the latest version of the application are :

- for Mac OS X (February 2019): Supported by 10.13 (High Sierra) and later

- for Windows 64 bits (February 2019): Supported by Windows 10

- for Linux (February 2019): Supported by Ubuntu v18 (Linux)

If your system does not support this version CM 2.0, you can download the previous versions CM 1.1 or CM 1.5 from the same Web site.

For further information on the software, send an email to : support@chronomodel.fr

2   Installation

From the website (www.chronomodel.com), you can download the software adapted to your computer.

- For MAC
  Click on the "MAC Download" button. Mount the DMG file by clicking on it and drag the Chronomodel.app icon to the Applications alias icon.
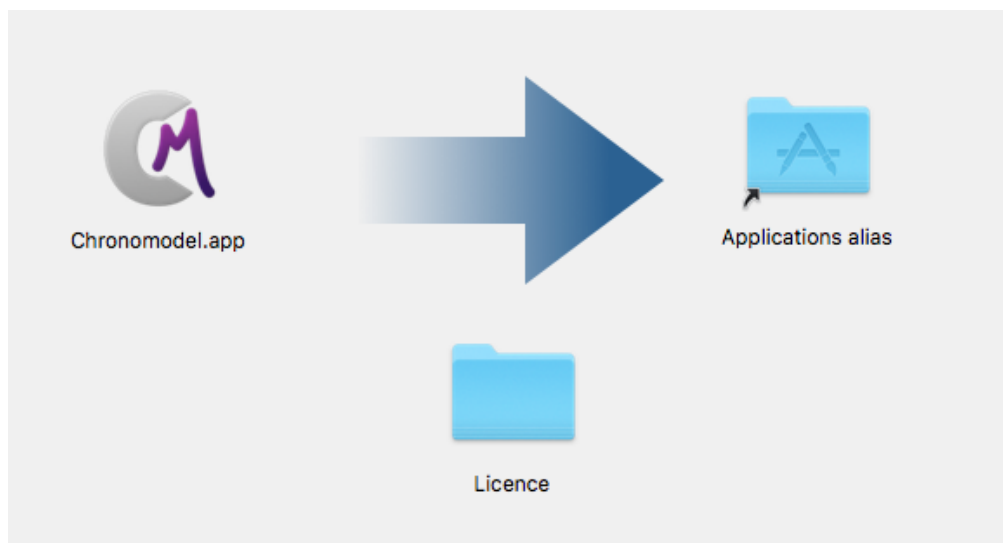
  Then double-click on the package to install the software. Following the wizard window, the software is installed in the Applications directory. Once done, the ChronoModel logo should be seen in the Applications directory.

- For Windows
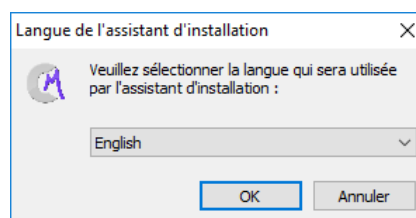
  You must have administrator rights to perform a proper installation. Click on the "Windows Download" button. Then double-click on the .EXE to install the software. And follow the general instructions to install ChronoModel with all its components. You may have to download a program from Windows to install the addon.

- For Linux

  We have made packages for Ubuntu. Click on the "Ubuntu Download" button. Open a terminal inside your download folder and type

  ```
  1    $ sudo dpkg −i chronomodel*
  ```

  To use chronomodel, launch "chronomodel" on a terminal.

- If your system is not proposed

  You can download the source code and compile everything yourself from scratch. It is built on Qt5 (Qt is a C++ toolkit for cross-platform application development - Qt is The Qt Company Ltd product developed as an open source project. See https://www.qt.io/ for more information.) and uses the FFTW library (http://www.fftw.org/).

  The only pre-requisite to build it yourself is to install Qt5 on your system. The project is hosted on GitHub.com. You can clone the repository by typing :

  ```
  1    $ clone https://github.com/Chronomodel/chronomodel.git
  ```

  and compile the application yourself.

3   Opening ChronoModel

3.1   Main window

After having launched ChronoModel, the following interface appears (See Figure 1).
At the moment you are not ready to start building a model. The main menu just
manages the model.
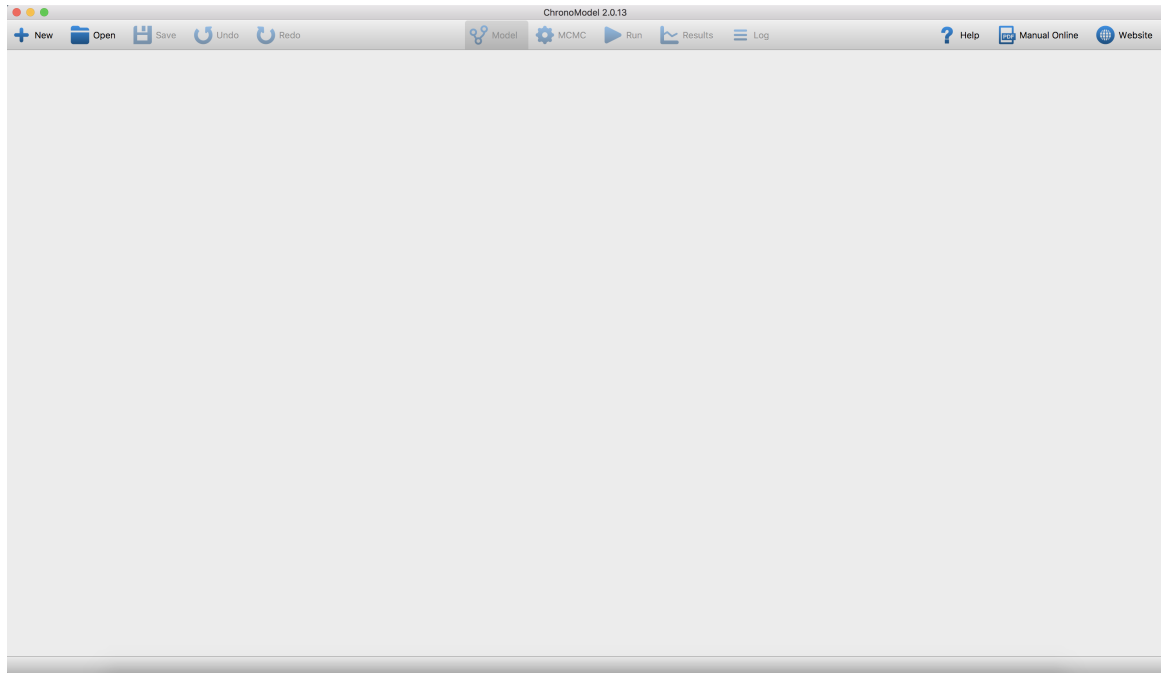
Figure 1 – ChronoModel interface

The design of ChronoModel is implemented with the following idea : *Information
is in the middle of the interface and the tools are around.*

3.1.1   Main menu

Depending on your system the main menu can appear differently.
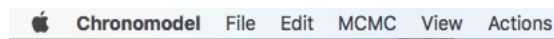
Figure 2 – on MacOS
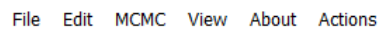
Figure 3 – on Windows

With the File menu, you can find the usual tools to create a New project, to
 Open an project, to Insert an project in the current project, to Close the current
project, to Save the current project and to Save as the current project with a
different name.
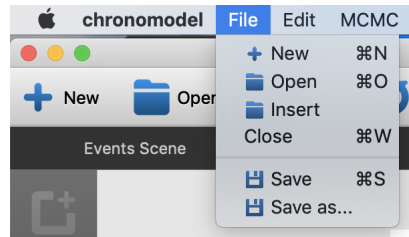
Figure 4 – Top Menu File

With the Edit menu, you can Undo or Redo the last action on the scene.
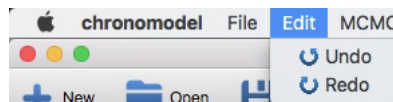
Figure 5 – Top Menu Edit

With the MCMC menu, you can execute a Run or an MCMC setting, and Reset Events Data Methods . The latter restores all default sampling methods in all Events and all Data. The Data sampling method depends on the dating method.
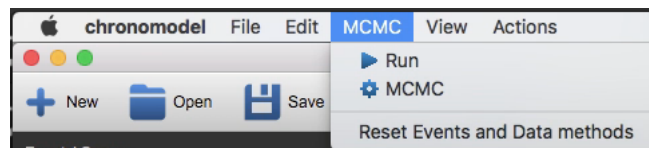
Figure 6 – Top Menu MCMC

With the View menu, you can navigate to the different windows of ChronoModel: Model or Results or Log . The Results and Log menus are not enabled since no Run has been processed.

Figure 7 – Top Menu View

With the Actions menu, you have miscellaneous tools.

Select All Events of the Selected Phases When a Phase is selected, ChronoModel selects, in the Events scene, the corresponding Events belonging to this Phase. A second part of the menu shows tools for grouped actions on selected Events: Selected Events: Change Color A color dialog box appears, you choose a color and all selected Events have their color changed.

Selected Events: Change Method A dialog box appears and you have to select the method you want to apply to the selected Events.
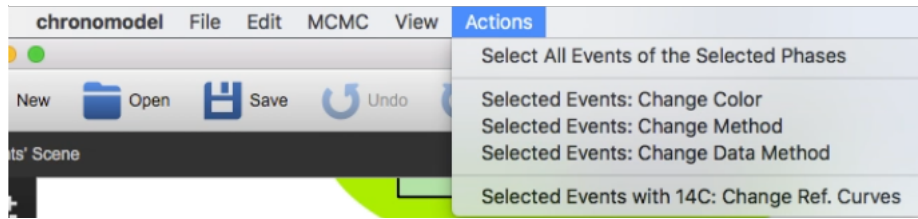
Figure 8 – Top Menu Actions
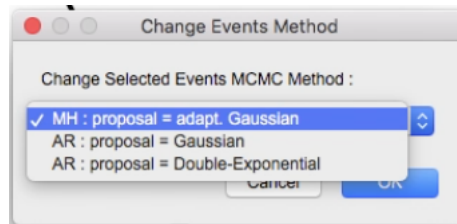
Figure 9 – Change Events method

Selected Events: Change Data Method Here, you have to firstly choose which type of Data you want to modify and after, in the second window, you choose the method to apply.
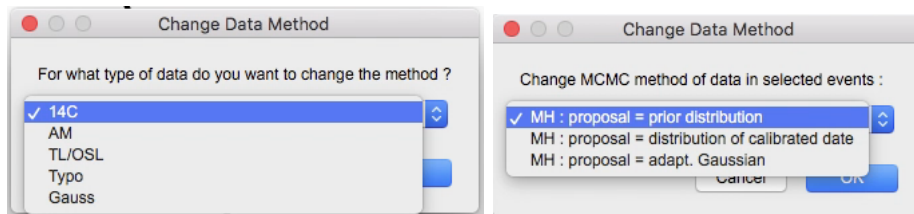
Figure 10 – Change Events method

A third part of the menu shows a tool for grouped actions only on 14C in selected Events to change the reference curve in all 14C Data.
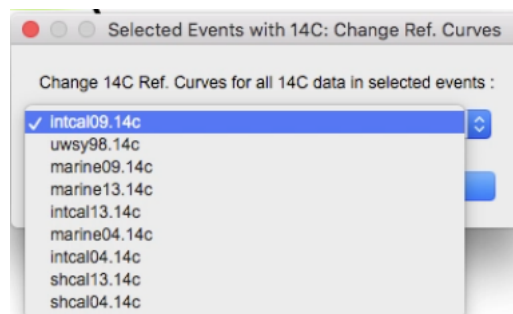
Figure 11 – Top Menu change reference curve for 14C

3.2 Application Settings

According to your system, the configuration of the interface can be found in the sub-menu Preferences in MacOS, or Settings in Windows.
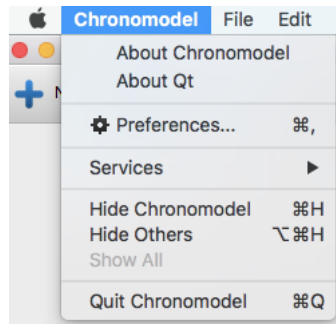
Figure 12 – in MacOS
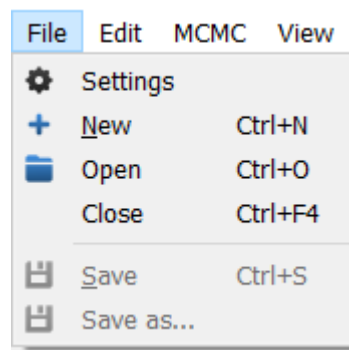
Figure 13 – in Windows

With the Application Settings window, you can customize some app behavior. On the left side, you can access to the general ChronoModel settings, or each Data plugin setting.

3.2.1 Language

The language setting defines how a number input should be typed, using a comma or dot as a decimal separator. This is not related to the application translation which is not yet implemented!

3.2.2 Font Menu

This button gives you the possibility to change the font used in the application. Here, you can change the size of the font and ChronoModel redraws the windows and resizes them. If you have a small screen, you can use it to adapt all windows.
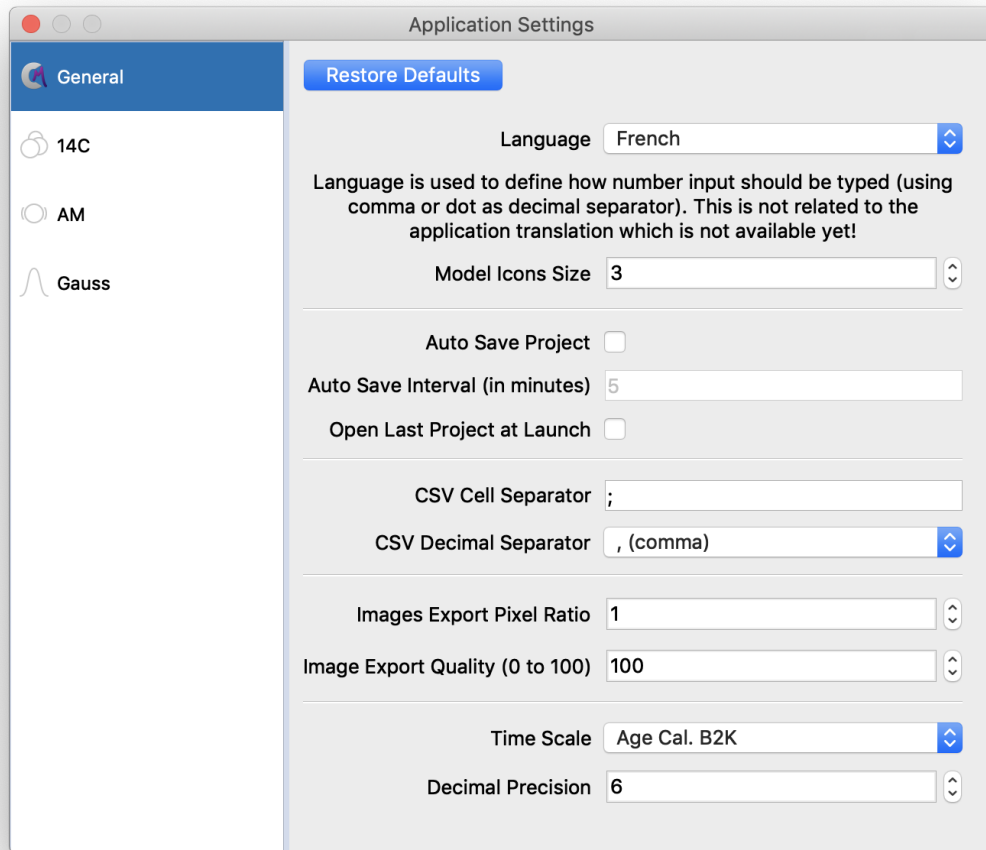
Figure 14 – Application Settings

3.2.3   Auto save

The Auto save project checkbox offers the possibility of setting a timed automatic backup. The elapsed time is set with the Auto save interval field.

3.2.4   CSV format

To exchange Data (import and export) with the app, you need to set the CSV format. The CSV cell separator fixes the character used to separate the fields/columns. The CSV decimal separator defines the decimal character.

    This is a text file format; that means, you can open your file with a simple text editor and modify it if necessary. The CSV format is not standardized. There are two main configurations:

- UK format; the character for the decimal separator is the dot, and for the cell separator, it is the comma.

- FR format; the decimal separator is the comma, and the cell separator is the semicolon.

In the settings, you are free to use any character for the separator, but you must use the comma or the dot as decimal separator. In this format, you do not have to use a space as the thousands separator. To know which characters are used in a file produced with a spreadsheet, just open it with a simple text editor. *Remember: most of the difficulty in importing Data comes from the bad settings of the CSV format. Sometimes, if the file comes from an other OS, the line end character can be different.*

3.2.5 Image quality

The Image Export Pixel Ratio sets the quality of the figure exported from the app, at between 1 and 5. The ratio of 5 is the best quality. But your file can be heavy ! The Image Export Quality (0 to 100) is a compression quality useful with the jpg image format. The quality *0* corresponds to the less compressed file, but with greater weight.

3.2.6 Date format

The Time Scale changes the displayed results, using different date formats.

- BC/AD : Before Christ / Anno Domini. This is the ChronoModel internal time t unit system.

- Age cal. BP: Ages calibrated Before Present. Corresponds to *1950 - t*

- Date cal. BP: Dates calibrated Before Present. Corresponds to *t - 1950*

- Age cal. B2K: Ages calibrated Before 2000. Corresponds to *2000 - t*

- Date cal. B2K: Dates calibrated Before 2000. Corresponds to *t - 2000*

- BCE/CE: same as BC/AD

3.2.7 Decimal Precision

This Decimal Precision parameter is used to change the number of digits on the displayed results, in all boxes and graphs. It can be set in a range of 0 to 6 digits.

3.2.8   Reference curves for calibration

On the left part of the Application Settings window, you can see a Data plugin with reference curves. By clicking on a plugin icon, you display the list of the reference curves according to the Data method. You can Add or Delete a file curve with the corresponding button at the bottom of the window. Be careful: do not delete a reference curve used in your model ... Each plugin needs a particular file format. If you see a file name written in red, it has a bad format.

3.3   Project tools

This section gives a description of all icons contained at the top of the window.
On the left-hand side of the main window, three icons help manage projects and two icons help managing modeling actions.

Create a new project. This is certainly the first icon you must use.

Open a pre-existing project. ChronoModel projects are saved using the extension file "chr".

Save the current project.

Undo the last actions.

Redo the last actions.

In the middle of the window, the icons refer to different steps of the modeling with ChronoModel.

Design the model.

Open the MCMC settings window.

Run the Bayesian modeling.

Show the results of the modeling.

Show summaries of the MCMC methods used for this modeling and its results.

Then on the right-hand side of the window:

Help Activates or deactivates the context-sensitive tips seen in yellow bubbles. By defaults, Help is active.
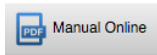
Manual Online Reaches the user manual on the web site.

Website Link to the ChronoModel website.

3.4   Create a project

In order to create a new project, click on [+ New] on the left-hand side of the window. This action opens a new window asking you to name this new project and to save it in a chosen directory.

Once done, a dialog box immediately appears and asks you to define the study period (see Figure 15).
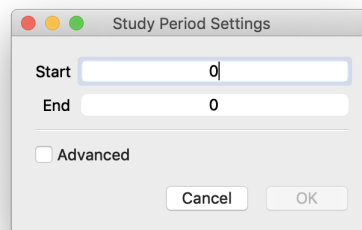
Figure 15 – Dialog box to define the study period

This is actually the first thing to do otherwise no other action will be allowed. The study period is the period under which you assume that the unknown calendar dates of the Events are likely to be. These pieces of information can be modified by clicking the boxes on the middle of the main window (See Figure 1).

The study period must be given in the date format BC/AD [1] as Bayesian modeling is computed in this date format.

For the example, let's use a study period from 0 to 2 000 (BC/AD).

Now the interface looks like Figure 16, the left-hand side side represents the Events scene and the right-hand side the Phases scene.

In ChronoModel, the Events scene and the Phases scene are separated in order to keep the design of the model comprehensible. Indeed, an Event may belong to several Phases. Moreover, the Phases scene may be placed side by side with the Events scene, in order to have a complete look at the design of the model. If needed, the windows separator can be moved to increase or decrease the width of both scenes.

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[1]Before Christ / Anno Domini
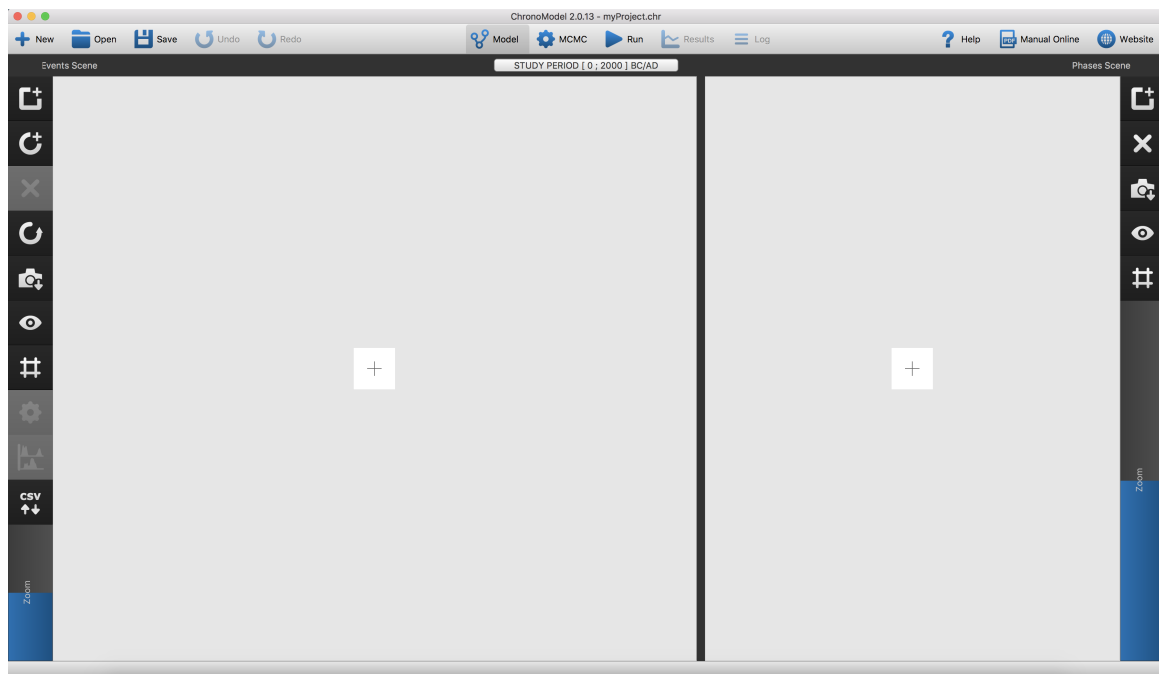
Figure 16 – The interface of ChronoModel when starting a new project. On the left-hand side of the window, the Events scene, on the right-hand side, the Phases scene.

3.5   Opening an existing project

To open a pre-existing project, use the [Open] on the top left of the window and then choose the project. ChronoModel projects are saved with the extension *.chr*.

When you load a heavy project, you can see a window with a progress bar, since the project is not recreated.
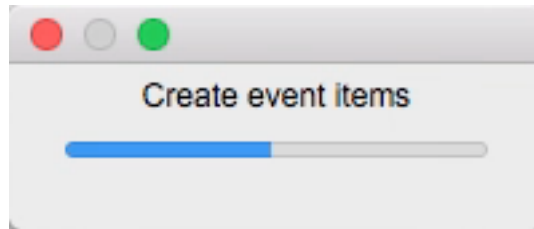
If you do not have the auxiliary file "chr.cal" near your model, in the same folder, ChronoModel rebuilds all the calibrations in order to draw the thumbnail of each Event item. It means that, to share your project, just share the file with the extension ".chr".
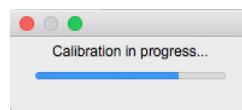
Figure 17 – Calibration computation on the full model

When you open a project built with an older version of ChronoModel, it triggers a warning message. If you are sure, accept to open by selecting Yes.
If you are unsure about compatibility, just make a copy of the project and test it.
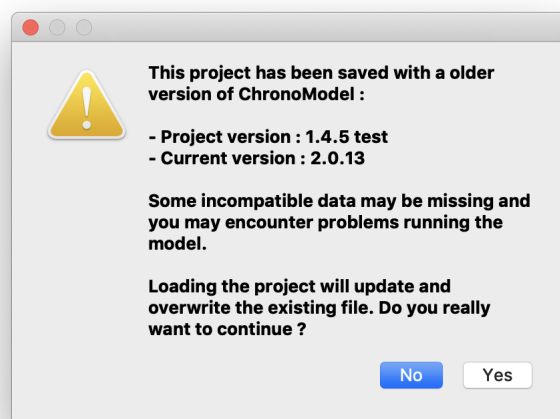
ChronoModel can detect whether your project has been built with an other release, maybe the same major version but not the same minor or build number (ChronoModel versioning scheme: major.minor.build). In that case a dialog message appears to confirm the opening of the auxiliary calibration file accompanying the project file (with the extension "chr.cal"). If in doubt, this auxiliary file "chr.cal" can be ignored.
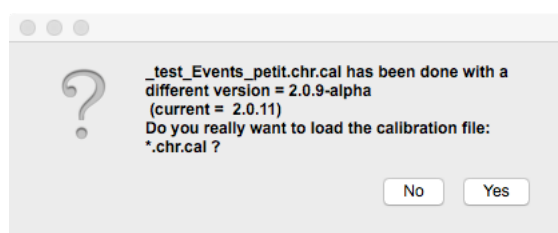
3.6   Changing the Study Period

At the top of the model windows, if you click on the study period information, you access the setting of the Study Period (see Figure 15). *For the time being, these values must be in BC/AD.*
With the setting box, there is a checkbox named Advanced . If you check this option, you can access more settings.
The first option is a checkbox entitled Force resolution . By default, the resolution of the calibration density in ChronoModel is 1 year. In some cases, often when doing theoretical tests, you can change this setting. In this case, you check it and you can change the value in the Resolution in years . We recommend leaving the default. If you change these values, ChronoModel recomputes all the calibrations. With large models, this calibration process could be much longer.
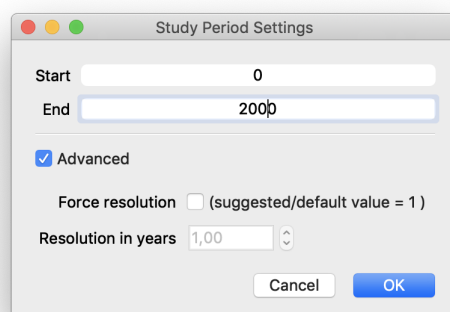
Figure 18 – Advanced option in the study period setting

4   Model: Events scene

4.1   Creating an Event

To create a new Event, select [icon] on the left-hand side of the Events scene (see Figure 16). A window will be opened asking you to name this new Event. For example, let's call it "My Event 1". A default color is given to this new Event but you may wish to change it. Click on the color chosen by default and select a new color from the Colors window.
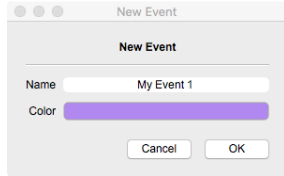
Figure 19 – Basic dialog box for the Event

Figure 20 – Dialog box to change the color of the Event item

After validation, the Event appears in the Events scene (See Figure 21).

4.2   Modifying an Event

Now, when the Event is selected in the Events scene, i.e. when the Event is circled by a red outline, the Event properties can be seen on the right-hand side of the window, using the [icon] button which is located on the left panel. From there, the name, the color and the MCMC method associated with this Event can be changed. For the MCMC sampling, the Method may be:

1. AR: proposal = Double-Exponential

2. AR : proposal = Gaussian

3. MH : proposal = adapt. Gaussian random walk (this is the default setting)
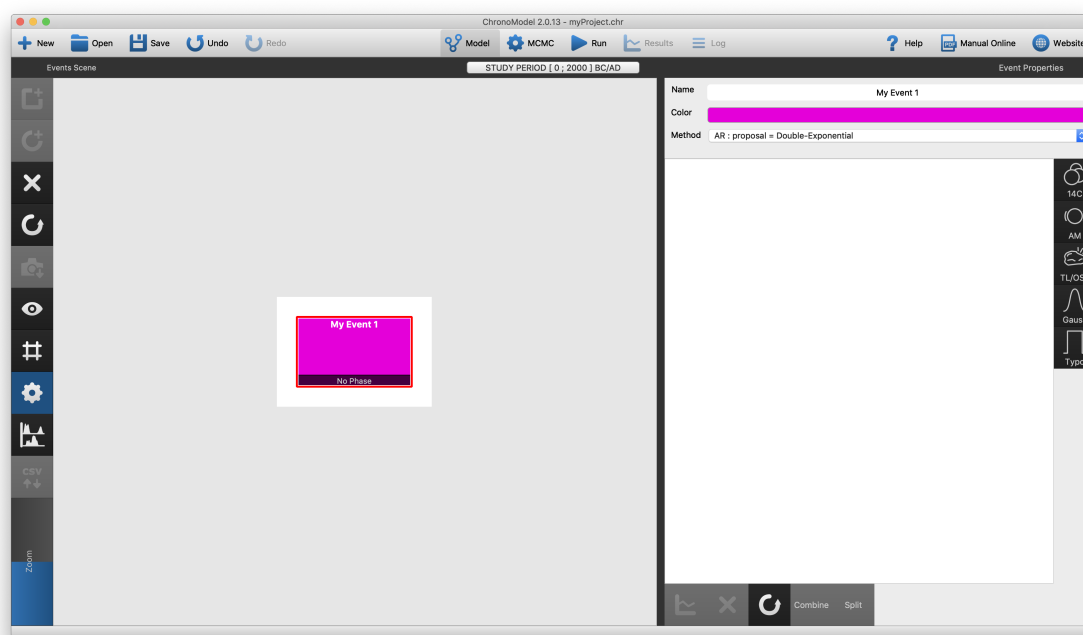
Figure 21 – Chronomodel window showing the new Event in the Events scene

4.3   Including individual dating Data

An Event may be associated with Data information such as measurements or typo-chronological references. There are two ways to insert Data with ChronoModel:

With [⚙]   Select the Event in which you want to add a measurement. An Event is selected when its outline is red. Then select a measurement type by clicking on a measurement icon on the right-hand side of the Properties panel and include information measurement by measurement. Details are given for each type of measurement in the following sections.

With [CSV]   Deselect any Event by clicking on an empty space of the Events scene and click on Load CSV file ... to include information from a CSV file. However, the CSV file has to be organized according to the type of measurements included (more details are given in the following sections). Then, you can drag a selected line to the corresponding Event.
In version 2.0, we add a column in the CSV file with the name of the Event containing the date. So now, if you drag a pack of dates onto an empty space of the Events scene, ChronoModel makes new Events with the name in the first column and inserts dates inside the corresponding Event. In the table, you can directly change the values of dates (not the Event name), but you can not save this table.

Be aware that by default ChronoModel reads a CSV file using a comma as a cell

Figure 22 – Inclusion of information dragged from a CSV file
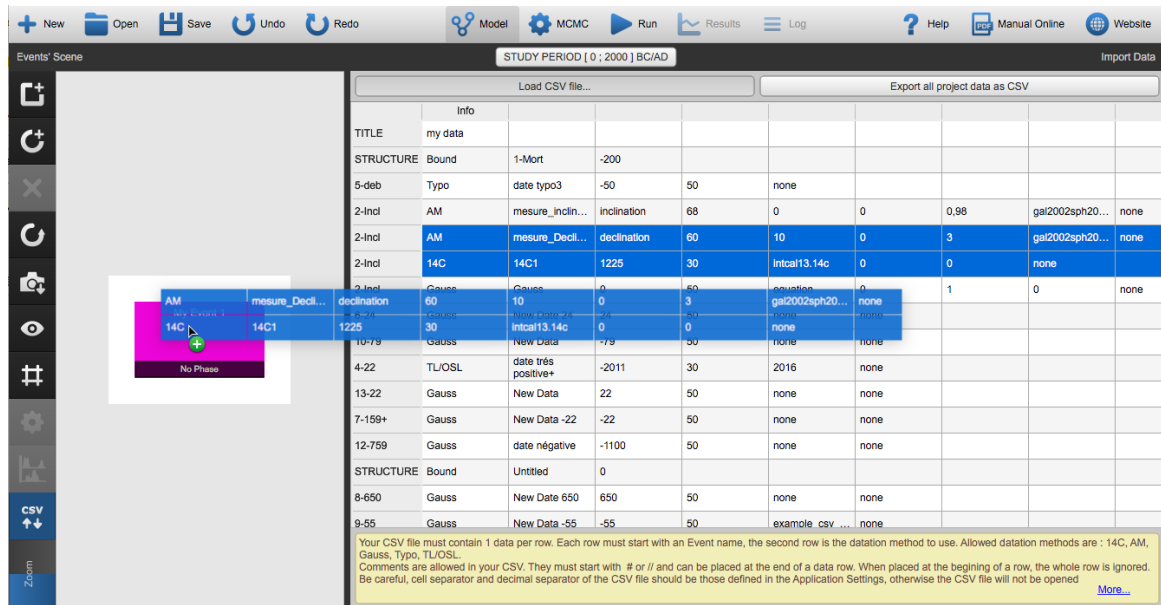
separator and a dot as a decimal separator. In the Application Settings presented
in Figure 23, these options can be changed.
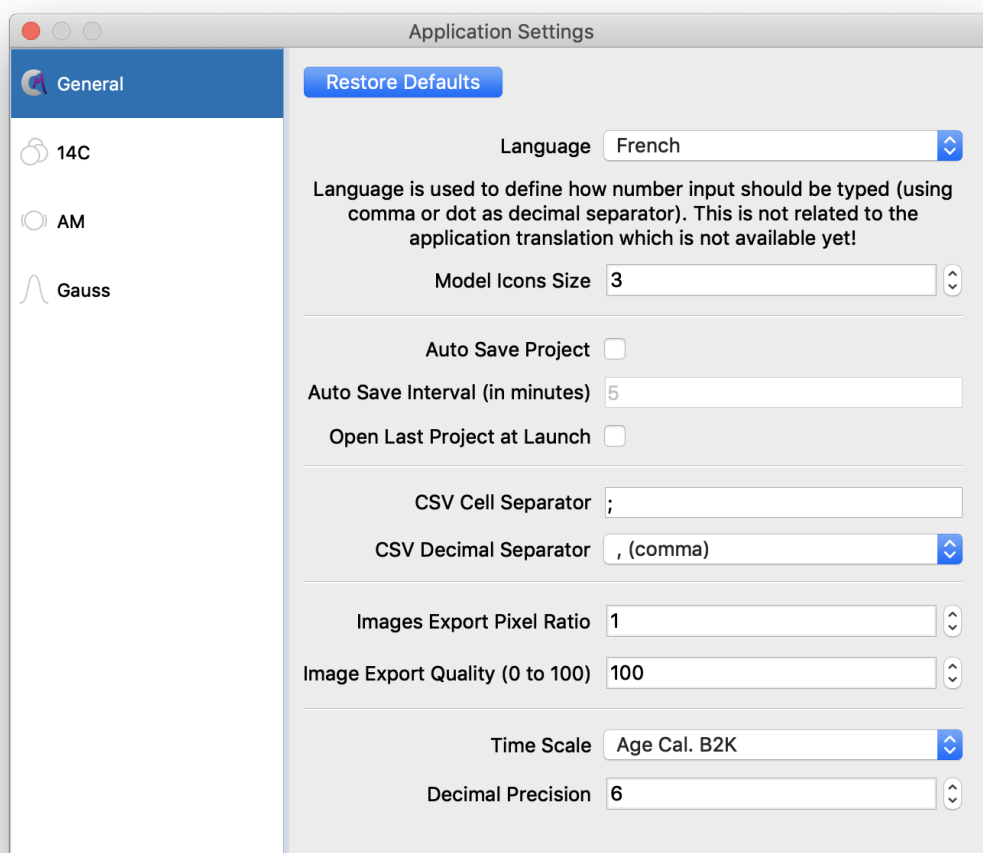
Figure 23 – Application settings

4.3.1   Radiocarbon date (14C)

Clicking on , the radiocarbon extension window will be opened (See Figure 24). Within this window, you can insert the reference name of the measurement, the age value given by the laboratory (Age), its associated standard error (Error), the reservoir effect ΔR with its associated standard error $\Delta R\,Error$ (data base: http://radiocarbon.pa.qub.ac.uk/marine/).

4.3.1.1   Reference curves   In ChronoModel, several calibration curves are already implemented. These curves are listed in Table 1. When adding a radiocarbon date, you can select one of these reference curves using the drop-down menu. Other curves may be included in ChronoModel from the Application Settings . Figure 25 shows the window from which it is possible to add a new reference curve.

Figure 24 – The radiocarbon measurement extension window with advanced options

Name	Reference
Uwsy98	Stuiver et al. (1998)
IntCal04	Reimer et al. (2004)
Marine04	Hughen et al. (2004)
ShCal04	McCormac et al. (2004)
IntCal09	Reimer et al. (2009)
Marine09	Reimer et al. (2009)
IntCal13	Reimer et al. (2013)
Marine13	Reimer et al. (2013)
ShCal13	Hogg et al. (2013)

Table 1 – Reference curves for 14C dating implemented in ChronoModel

4.3.1.2   Advanced options   You can change the MCMC method used to sample from the posterior distribution of the calibrated date associated with that dating: see Lanos and Philippe (2017, 2018) for more details. To do this, click on the Advanced menu from the same window (See Figure 24).

The default MCMC method used for radiocarbon dating is the Metropolis Hastings
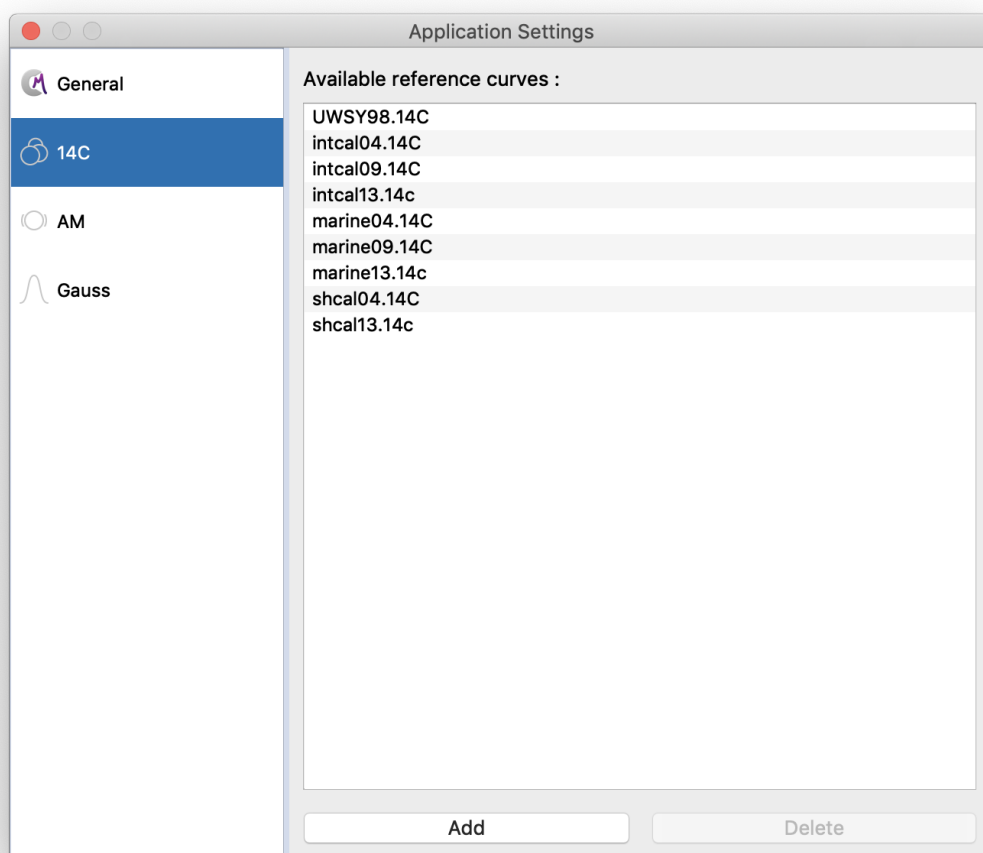
Figure 25 – Application Settings - Reference curves for 14C date

algorithm using a distribution that mimics the individual calibration density as a proposal. Two other proposals may also be selected, a prior distribution and an adaptive Gaussian random walk.

Once the measurement is validated, its details appear in the Properties tab as shown in Figure 26 and can be changed by double-clicking on its name from the list of measurements.

4.3.1.3 Wiggle Matching (via Advanced options) You may want to include wiggle matching. The wiggle matching may be fixed or included within a range of values or even have a Gaussian distribution defined by its mean value and its standard error. By default, the wiggle matching is set to 0.

4.3.1.4 Combining radiocarbon ages Several radiocarbon measurements referring to a unique sample may be "combined". These radiocarbon measurements
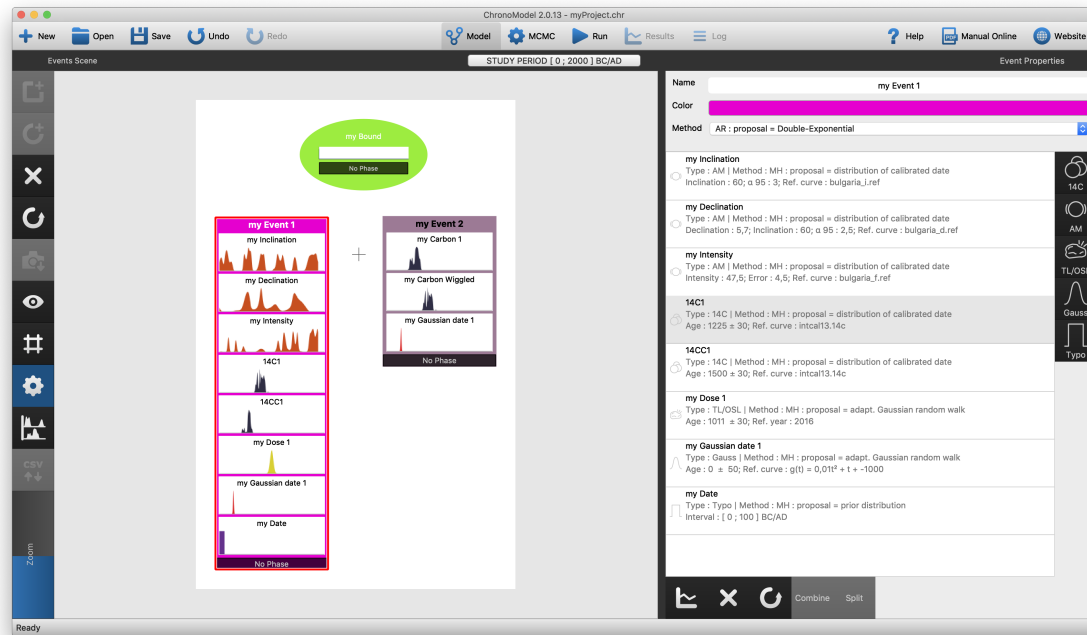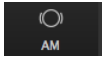
Figure 26 – Events scene and Properties

should have the same reference curve for the calibration and the same MCMC method. To "combine" several measurements, select the associated Event in the Events scene, then select the Properties button. Now select all measurements to be combined from the list of measurements and click on [Combine] at the bottom of the window. Now a unique measurement appears marked by ⓒ. Click on [Split] to split back the measurements.

4.3.2 Archaeomagnetic date (AM)

Click on [AM] to open the extension window associated with archaeomagnetic dating, as displayed in Figure 27. Within this window, you can insert the reference name of the measurement, you can choose the magnetic parameter (inclination, declination or intensity) and insert values. You can also choose the reference curve for the calibration process.

- If you choose Inclination : enter its value and its alpha 95 value. The associated error is then calculated by

$$\frac{\alpha_{95}}{2.448}$$

- If you choose Declination : enter its value, the value of the Inclination associ-

Figure 27 – The archaeomagnetism extension window with advanced options

ated and its associated alpha 95 value. The associated error on the declination is calculated by

$$\frac{\alpha_{95}}{\cos(Inclination) * 2.448}$$

- If you choose Intensity : enter its value and its Error .
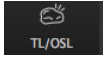
4.3.2.1   Reference curves   Several reference curves are implemented in ChronoModel. They are listed in Table 2. Other curves can be included in ChronoModel from the Application Settings . See Figure 25 that shows the windows allowing to add a new reference curve.

Name	Reference
Gal2002Sph2014_D	Hervé et al. (2013a,b)
Gal2002Sph2014_I	Hervé et al. (2013a,b)
Gws2003uni_F	Hervé et al. (2013a,b)
Bulgaria_D	Kovacheva et al. (2014)
Bulgaria_I	Kovacheva et al. (2014)
Bulgaria_F	Kovacheva et al. (2014)

Table 2 – Reference curves implemented in ChronoModel

4.3.2.2   Advanced options   You may want to change the MCMC method used
to sample out of the posterior distribution of the calibrated date associated with
that date (See 6 section for more details on MCMC methods). The default MCMC
method used for archaeomagnetism date is the Metropolis Hastings algorithm using a
distribution that mimics the individual calibration density as a proposal. Two other
proposals may also be selected, a prior distribution and an adaptive Gaussian random
walk.

4.3.3   Luminescence date (TL/OSL)

Click on [TL/OSL icon] to open the TL/OSL extension window as shown in Figure 28. A
TL/OSL measurement is defined by its name, its Age , its Error (sd) and the year
of reference Ref. year .

4.3.3.1   Reference year   The function of calibration associated is then

$$g(t) = t_0 - t$$

, where t_0 is the reference year.

4.3.3.2   Advanced options   You may want to change the MCMC method used
to sample from the posterior distribution of the calibrated date associated with that
dating method (See 6 section for more details on MCMC methods). The default
MCMC method used for TL/OSL date is the Metropolis Hastings algorithm using
an adaptive Gaussian random walk as a proposal. Two other proposals may also be
selected, a prior distribution and a distribution that mimics the individual calibration
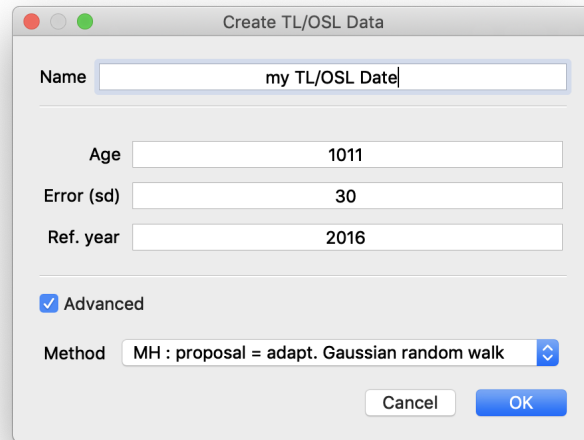density.

Figure 28 – The paleodose measurement in luminescence extension window with advanced options

4.3.4 Gaussian dating (Gauss)

Click on [Gauss] to open the Gauss extension window as presented in Figure 29. A Gaussian date is defined by its name, its mean $\boxed{\text{Measurement}}$ and its error $\boxed{\text{Error}}$ $\boxed{\text{(sd)}}$. Measurement and Error are defined in *date format BC/AD*.

4.3.4.1 Reference curve For the Gaussian date, the calibration process follows a quadratic function:

$$g(t) = a * t^2 + b * t + c$$

If $a = c = 0$ and $b = 1$, then $g(t) = t$ i.e. the calibration function is the identity function (i.e. no calibration). This is the default choice corresponding to the option $\boxed{\text{None}}$.

You can also customize your own calibration curve using the option $\boxed{\text{Build your equation}}$. The parameters a, b, and c can be changed.

Since ChronoModel version 1.5, a third option has been implemented. You can load a CSV file containing a different calibration curve. To do this, select the last option $\boxed{\text{Use custom curve file}}$ and choose a file from the drop-down menu. If your file is not already included in ChronoModel, use the $\boxed{\text{Application Settings}}$ window to add/delete another file. See Figure 25 that shows the window allowing to add a new reference curve for the radiocarbon date.

4.3.4.2   Advanced options   You may want to change the MCMC method used
to sample from the posterior distribution of the calibrated date associated with that
date (See 6 section for more details on MCMC methods). The default MCMC method
used for Gaussian date is the Metropolis Hastings algorithm using an adpative Gaus-
sian random walk as a proposal. Two other proposals may also be selected, a prior
distribution and a distribution that mimics the individual calibration density.

4.3.4.3   Wiggle Matching (via Advanced options)   As for radiocarbon dat-
ing, we can include wiggle matching. The wiggle matching may be fixed or included
within a range of values or even have a Gaussian distribution defined by its mean
value and its standard error. By default, the wiggle matching is set to 0.

Figure 29 – The Gaussian measurement extension window with advanced options

4.3.5   Typo-chronological reference (Typo Ref.)

Click on ⬚ to open the Typo-reference extension window (See Figure 30). A Typo-
reference is defined by its Name , its Lower date and its Upper date , with the

constraint that the ☐Lower date☐ is the more ancient date. A Typo-reference date is assumed to be defined in *date format BC/AD*

4.3.5.1 Advanced options   You may want to change the MCMC method used to sample from the posterior distribution of the calibrated date associated with that date (See 6 section for more details on MCMC methods). The default MCMC method used for typo-chronological reference is the Metropolis Hastings algorithm using an adaptive Gaussian random walk as a proposal. The other proposal that may also be selected is prior distribution.
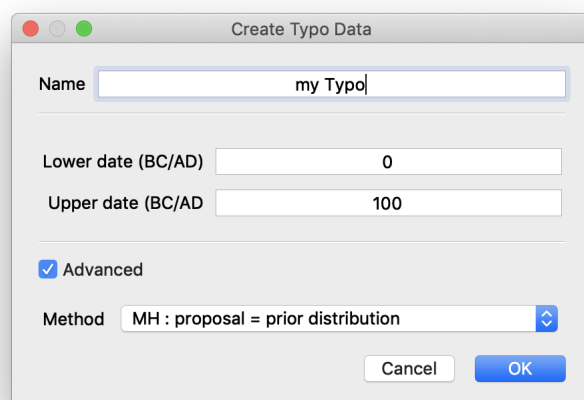
Figure 30 – The Typo-reference extension window with advanced options

4.3.6 Individual calibration process

For each measurement, it is possible to see the result from the individual calibration process. First, select the associated Event from the Events scene. Then, select the measurement from the ⚙ button and click on ⬚ at the bottom of the Properties panel.

At the bottom of the drawing, you have classical statistics on the calibration curve.

On the left-hand side of the calibration panel, you can modify the date period shown ☐Start☐ and ☐End☐ , on the axis, the major interval ☐Maj. Int☐ is the interval for the main division of the axes *in year* and a Minor interval Count ☐Min. Cnt☐ is the interval for the subdivision (*a number*) of the main division. And you can change the HPD threshold, all statistical results are computed on the study period defined
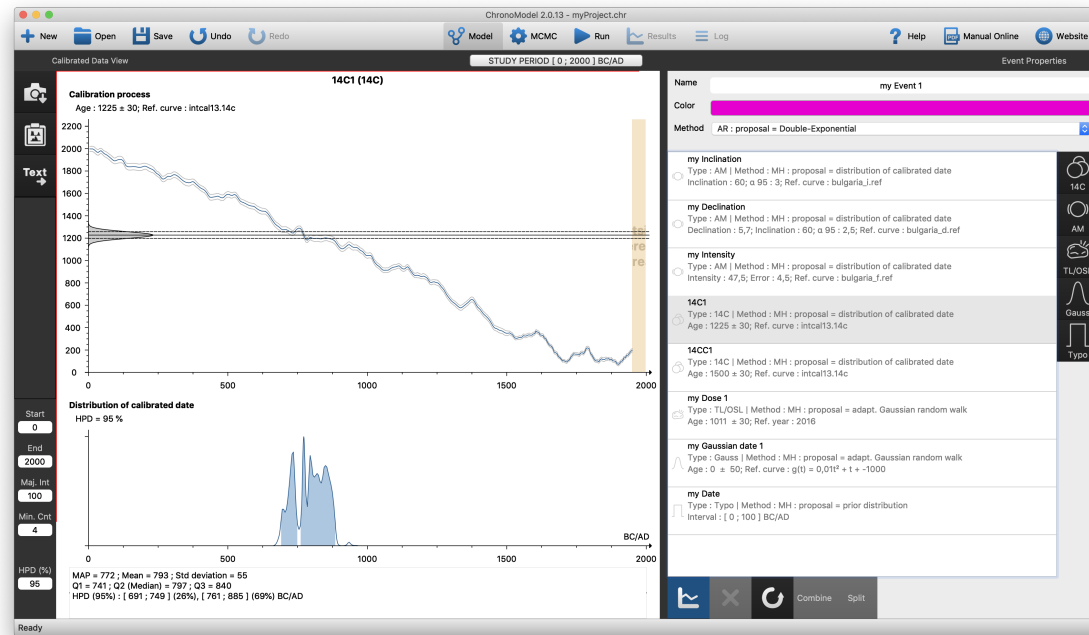
Figure 31 – Calibration process of a radiocarbon date

for the model and they are converted into the date format set in the   Application
Settings .

Deselect ⌊⊾ to see the Events scene again.

4.3.7   Deleting Data

To delete a measurement from an Event, first select the Event in the Events scene
by clicking on its name. The Event will be selected only if it is surrounded by a red
line. Then using the ⚙ button, you can select the measurement inside the left list
to be deleted and finally click on the ✕ icon situated on the right-hand side of the
window to delete it.

4.3.8   Restoring Data

A deleted measurement may be restored in a selected Event. Click on the ↻ icon
at the bottom of the window and choose the measurement to be restored from the
list of deleted measurements.

4.3.9   Moving Data to another Event

You can change the place of a Data. To do this, press the ⇧ button (shift) and drag (i.e. keep the left button of your mouse pressed) a Data thumbnail to another Event. When the other Event is detected, it is surrounded with a blue dashed line. Then you can release the thumbnail and the ⇧ button.
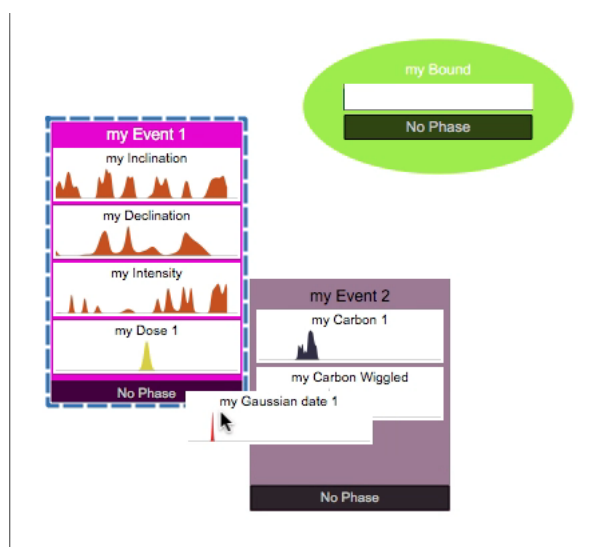
Figure 32 – Moving Data to another Event

4.4   Data transfer

The ![csv] button allows to import a CSV file containing information about Data and to export all Data used in the modelling of the current project.

Be aware that the cell separator and the decimal separator of CSV files are those specified in the Application Settings of ChronoModel, otherwise the CSV file will not be downloaded.

4.4.1   Importing Data

CSV files have to be organized in a specific way depending on the type of measurements (the type of the dating process). Each of the following pieces of information should be written in the same row but in a separate cell.

Cell 1: The first cell is the name of the Event

Cell 2: The method of measurement

Cell 3: Name, the name of the dated sample

4.4.1.1   Gaussian measurements

Example:

```
my Event 1;Gauss;my Measurement 1;24;50;none;none
my Event 2;Gauss;my Measurement 2;0;50;equation;0,01;1;-1000;none
my Event 3;Gauss;my Measurement 3;-55;50;example_csv_ref.csv;none
my Event 4;Gauss;my Measurement wiggled;0;50;equation;0,01;1;-1000;range;10;15
```

Description:

Cell 1: Event name

Cell 2: Gauss

Cell 3: Name

Cell 4: Age, the mean of the Gaussian measurement

Cell 5: Error (sd), the standard error of the Gaussian measurement

Cell 6: Ref. curve, one of the following options : "none" (if no calibration is needed) or "equation" (when specifying an equation) or the name of the file containing the reference curve to be used, present in the folder Gaussian in the `Application Settings` .

Now, if "none" or a CSV file is declared,

Cell 6: any text will be considered as a comment

Now, if "equation" is declared,

Cell 7: a, **Cell 8** : b and **Cell 9** : c

where a, b and c refer to the calibration curve. Indeed, in this case, the equation of the calibration curve is the following one:

$$g(t) = a * t^2 + b * t + c$$

The content of any following cells will be ignored (so these can be used for comments).

Cell 8 : Wiggle matching type if any : "fixed", "range" or "gaussian"

Any other word will be ignored by ChronoModel.

Cell 10: Wiggle matching value, the value if "fixed", the lower value if "range" or the mean value if "gaussian"

Cell 11: Wiggle matching value, the higher value if "range" or the standard error value if "gaussian"

4.4.1.2   Thermoluminescence measurements

Example:

```
my Event 1;TL/OSL;my Dose 1;-2011;30;2016;none
```

Description:

Cell 1: Event name

Cell 2: TL/OSL

Cell 3: Name, the name of the dated sample

Cell 4: Age, the value of the measurement

Cell 5: Error (sd), the standard error of the measurement

Cell 6: Reference year, the year of the dating of the sample

The content of any following cells will be ignored (so these can be used for comments).

4.4.1.3 Radiocarbon measurements

Example:

```
my Event 1;14C;my Carbon 1;1500;50;intcal13.14c;0;0;none
my Event 2;14C;my Carbon Wiggled;1225;30;intcal13.14c;0;0;range;10;15
```

Description:

Cell 1: Event name

Cell 2: 14C

Cell 2: Name, the name of the dated sample

Cell 3: Age, the value of the measurement

Cell 4: Error (sd), the standard error of the measurement

Cell 5: Reference curve, the name of the file containing the reference curve associated with the measurement

Cell 6: Reservoir effect, the value of the reservoir effect if any

Cell 7: Error of the reservoir effect, the value of the associated error, if any

Cell 8: Wiggle matching type if any : "fixed", "range" or "gaussian"

Any other word will be ignored by ChronoModel.

Cell 9: Wiggle matching value, the value if "fixed", the lower value if "range" or the mean value if "gaussian"

Cell 10: Wiggle matching value, the higher value if "range" or the standard error value if "gaussian"

The content of any following cells will be ignored (so these can be used for comments).

4.4.1.4 Archaeomagnetic measurements

Example:

```
my Event 1;AM;my Inclination;inclination;60;10;0;3;bulgaria_i.ref;none
my Event 1;AM;my Declination;declination;60;5,7;0;2,5;bulgaria_d.ref;none
```

```
my Event 1;AM;my Intensity;intensity;60;0;47,5;4,5;bulgaria_f.ref;none
```

Description:

Cell 1: Event name

Cell 2: AM

Cell 2: Name, the name of the dated sample

Cell 3: Method, "inclination", "declination" or "intensity"

Cell 4: Inclination value

Cell 5: Declination value

Cell 6: Intensity value

Cell 7: Error (sd) or alpha 95, the degree of alpha 95 associated with the inclination / declination value or the standard error associated with the intensity value

Cell 8: Reference curve, the name of the file containing the reference curve associated with the measurement

The content of any following cells will be ignored (so these can be used for comments).

4.4.1.5   Typo-chronological reference   Example:

```
my Event 1;Typo;my Date;-60;-50;none
```

Description:

Cell 1: Event name

Cell 2: Typo

Cell 3: Name, the name of the dated sample

Cell 4: Lower date

Cell 5: Upper date

The content of any following cells will be ignored (so these can be used for comments).

4.4.1.6   How to drag dating Data from the CSV file into the Events scene ?

Figure 33 displays an example of a CSV file loaded in ChronoModel. This file contains 6 Data : 3 archaeomagnetism measurements (inclination, declination and intensity), 2 radiocarbon measurements (the first with wiggle correction), 1 Gaussian measurement with wiggle correction and 1 typo. ref date. When a Data line is selected, the labels of each column are refreshed according to the type of Data.

Now, once the CSV file is loaded, Data may be included in an already existing Event. To do this, select the Data line to be included, keep clicking and drag it over an Event. Multiple selections may also carried out. If you drag lines over an Event,
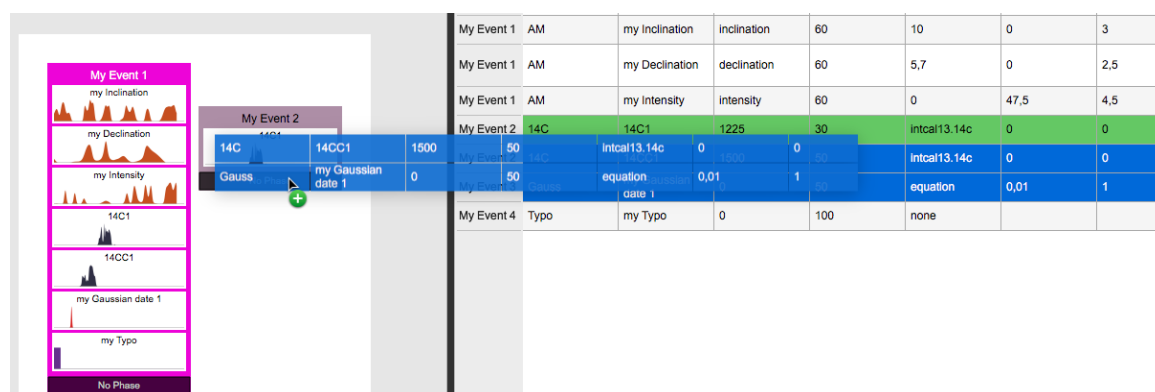
	Method	Data Name	Age	Error (sd)	Ref. curve	ΔR	ΔR Error	none | fixed | rang	1 (fixed | Lower d	alue 2 (Upper dat
TITLE	myproject.chr									
My Event 1	AM	my Inclination	inclination	60	10	0	3	gal2002sph20…	none	
My Event 1	AM	my Declination	declination	60	5,7	0	2,5	bulgaria_i.ref	none	
My Event 1	AM	my Intensity	intensity	60	0	47,5	4,5	bulgaria_f.ref	none	
My Event 2	14C	14C1	1225	30	intcal13.14c	0	0	range	10	15
My Event 2	14C	14CC1	1500	50	intcal13.14c	0	0	none		
My Event 3	Gauss	my Gaussian date 1	0	50	equation	0,01	1	-1000	range	10
My Event 4	Typo	my Typo	0	100	none					

Figure 33 – CSV file with 14C method selected

	Method	Data Name	type	Inclination value	Declination value	Intensity value	Error (sd) or α_95	Ref. curve	Comment	Comment
TITLE	myproject.chr									
My Event 1	AM	my Inclination	inclination	60	10	0	3	gal2002sph20…	none	
My Event 1	AM	my Declination	declination	60	5,7	0	2,5	bulgaria_i.ref	none	

Figure 34 – CSV file with AM method selected

Data will be added to this Event. If you release the selected lines over an empty space of the Events scene, ChronoModel builds Events with the names of the first column and inserts Data. If the same Event name appears several times in the table, the corresponding Data will be grouped in only one Event.

Figure 35 – Insert by dragging Data into an Event

If a line appears in green, this means that the Data has been attributed to an Event. If the line is colored in red, that means that the Data has not been attributed due to errors. In this case, ages and errors should be checked and modified before any use in ChronoModel.

4.4.2   Exporting Data

We can export the Data into a CSV file. On the top right in the CSV windows, there is a button Export all project data as CSV

By clicking, you can export all the Data from all the Events (but no Phase Data) in

a CSV file. This one has the same format as the import one.

Remember the value separator and decimal separator are set in the `Application Settings` *window* [3.2.4](#)

4.4.3   Hiding the Import Data panel

When you have finished importing or exporting Data, to hide the panel, deselect the button ⬛.

4.5 Creating a Bound 41

4.5 Creating a Bound

To create a new Bound in the Events scene, select [icon] on the left-hand side of the window. A new window will be opened asking you to name this new Bound.
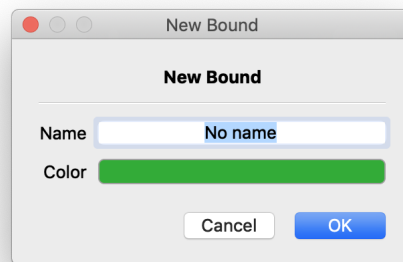
After validation, the Bound appears in the Events scene (See Figure 36). Now you need to switch on the property button [icon] to set its values.

From there, its name and its color can be changed and value can be set. In this version of CM, a Bound must have a fixed value because it operates as a TPQ or TAQ.

Figure 36 – Creation of a new Bound in the Events scene

4.6   Modifying a Bound

Click on a Bound and click the property button ⚙️ to access to the Bound's settings.

4.7   Deleting an Event or a Bound

An Event or a Bound can be deleted from the Events scene first by selecting the Event and then by clicking on the ✖️ button placed on the left-hand side of the Events scene. The Event is deleted with all its measurements.

4.8   Restoring an Event or a Bound

Any element deleted can be restored by clicking on the ↻ button on the left-hand side of the Events scene. Then the element to be restored can be picked from the new window presenting all deleted elements (Bounds or Events). See Figure 37: an Event containing measurements is restored with all its measurements, at the same place before deleting.
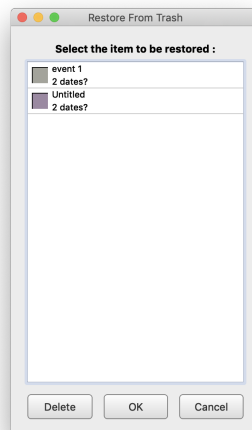

Figure 37 – Window presenting all Events or Bounds that can be restored

4.9   Ordering constraints between the Events

From the Events scene, a stratigraphic or succession constraint may be added between any two elements (Events and Bounds).

4.9.1   Creating an Events order

Select an Event. Hold the Alt key. Move the pointer over an younger Event in your chronology, a black dashed arrow will follow your movements. If the link is possible, the arrow becomes green with a label OK. If the link is impossible, the arrow becomes red with a white cross. Click and after release the Alt key to hang your link.

The arrow, in a continuous line, goes from the older Event to the younger Event.
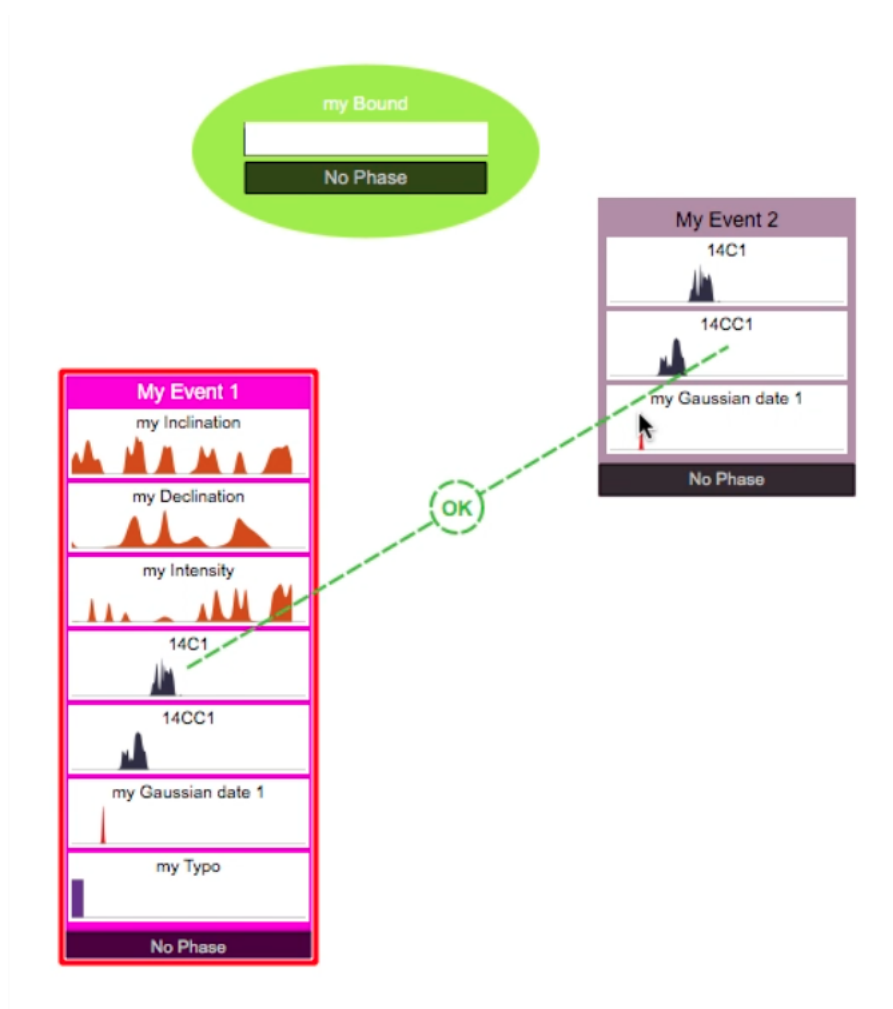

Figure 38 – Events scene showing a constraint between 2 Events

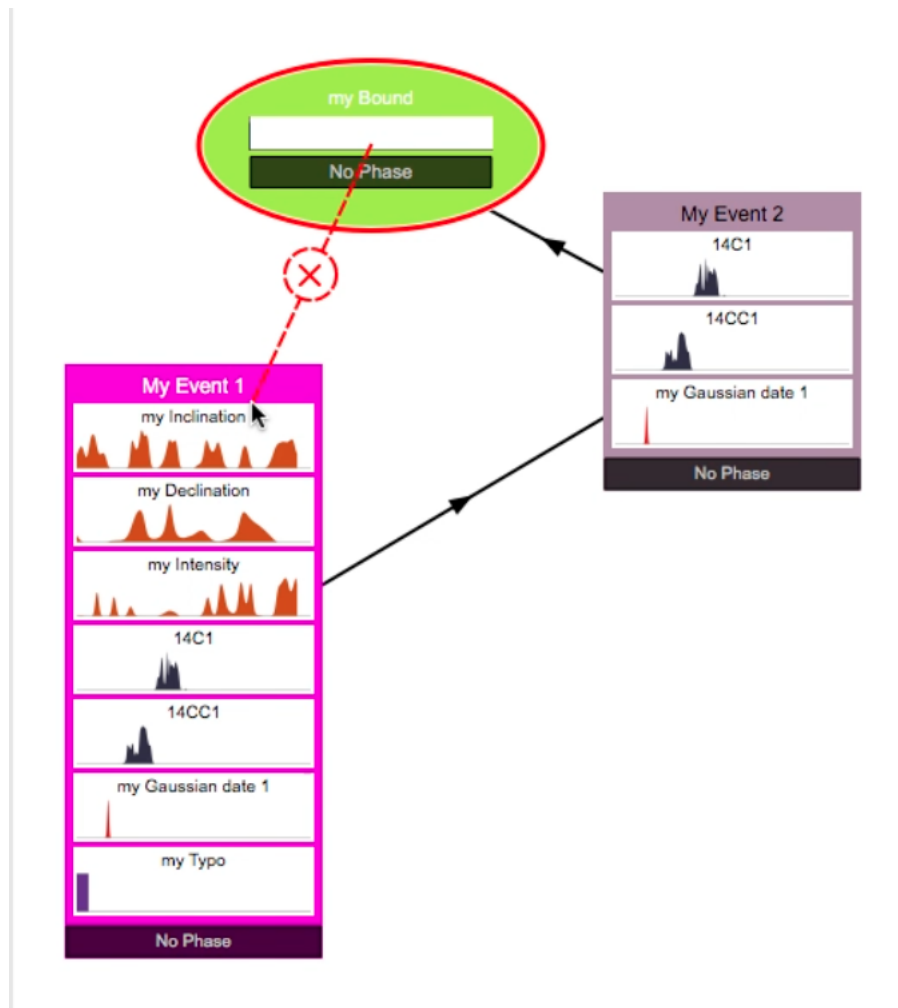In the following example, there is a circular constraint.

Figure 39 – Events scene showing a bad constraint between a Bound and an Event

4.9.2   Deleting an Events order

When the pointer passes over an order arrow, the arrow becomes red with a white cross in the middle. Click on the cross to remove the link and accept on the following window.

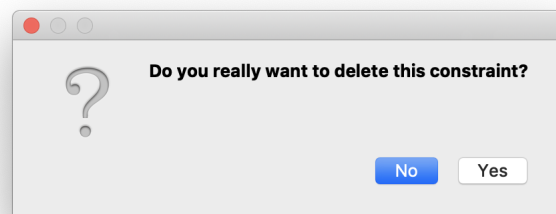Figure 40 – Events scene showing a constraint ready to be deleted

Figure 41 – Confirmation box to delete a constraint

4.10   Using the grid to align Event items

By default, the Events scene is white. A grid may be added using the [⊞] button situated on the left-hand side of the window. This shows a grey grid with a "magnetic effect", to help you to align Events.
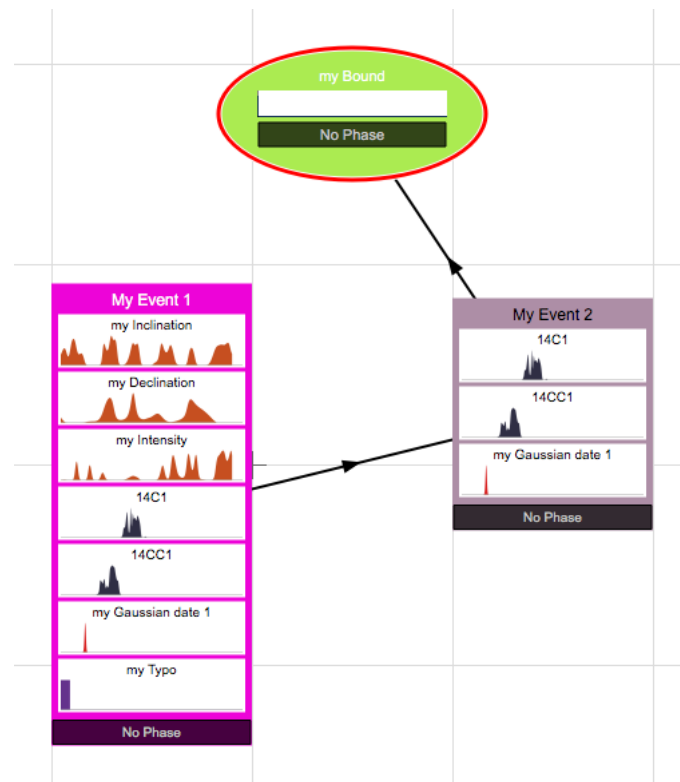

Figure 42 – Events scene with magnetic grid

4.11   Using the zoom to adapt the view

With the scroll of the zoom on the bottom left of the scene, you can adjust the view of the scene to see more or less items. A double click on the scroll reset the zoom to the default value.

4.12   Event or Bound search and overview

The overview may be useful when many elements are in the Events scene. To watch the Events scene from an overview use the 👁 button placed on the left-hand side of the Events Scene panel. A small window appears on the top left corner of the scene, showing all your Events in it. Inside, you can see a red square indicating the position of the current view. At the top of the overview window, there is an input box, where you can insert the name of an Event or the name of a date, you want to search for. When you finish editing the searched text, just type ⌨ (return) and the central view moves to the Event answering to the query. If there are several solutions, press ⌨ again and the view moves to an other Event which matches, if it exists.
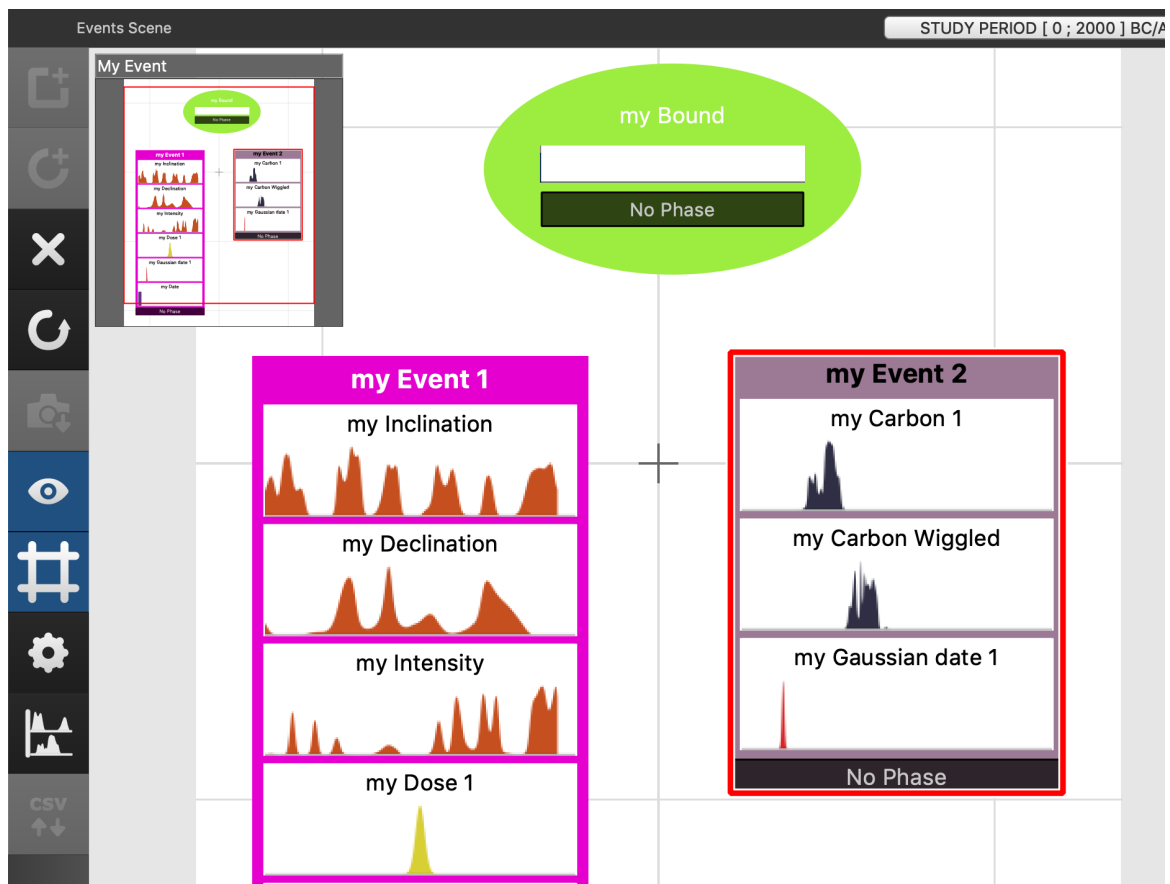

Figure 43 – Events scene showing answer to the Overview search

Remark: When you select Events which belong to Phases, they are highlighted inside the Phases. And when you select some Phases, Events included into them are highlighted in the Events scene. In fact, Events not in the selected Phases are shaded.

4.13   Exporting the image of the Events scene

You may also export the image of the Events scene by clicking on the [icon] button
and saving it either in PNG, JPG, BMP format or in Scalable Vector Graphics (SVG)
format. In both cases, you will need to name the image and to choose the directory
in which to save the image.

Remember : In Application Settings , you can change the Image Export Pixel Ratio
and Image Export Quality (see figure 14)

4.14   Multi-Plot of individual calibrated dates

In the new version of ChronoModel, you can plot several calibrated dates owned by
several Events. First you select one or several Events in the scene, using ⇧ (shift for
Windows and Linux) or ⌘ (cmd for Mac Os) depending on your system, and click
on the [icon] button.

On the left of each density, a colored flag recalls the color of the Event.

On the right, you can see tools working with the Multi-Calibration View

You can save an image as a file by clicking on the [icon] button, in either PNG,
JPG, BMP format or in SVG (Scalable Vector Graphics) format.

[icon] copies to clipboard either the values or the drawings.

[icon] button shows the statistics of the calibrated dates.

 Y zoom offers to change the size of all drawings. Less than 80%, the text under
the scale then disappears.

[icon] changes the color of all density curves.

In the same way as the calibration process, you can modify the date scale with
 Start and End . The major interval Maj. Int is the interval for the main division
of the axes *in year* and the Minor interval Count Min. Cnt is the interval for the
subdivision (*a number*) of the main division. You can change the HPD threshold.
Note that all the statistical results are computed within the study period defined for
the model and they are converted into the date format which is set in the Application
 Settings

To hide the panel, deselect in the Events Scene panel the button [icon], or click
on an empty space in the Events Scene .

Figure 44 – Multi-Calibration View and the Events scene

Figure 45 – Multi-Calibration View and the Events scene

5   Model: Phases scene

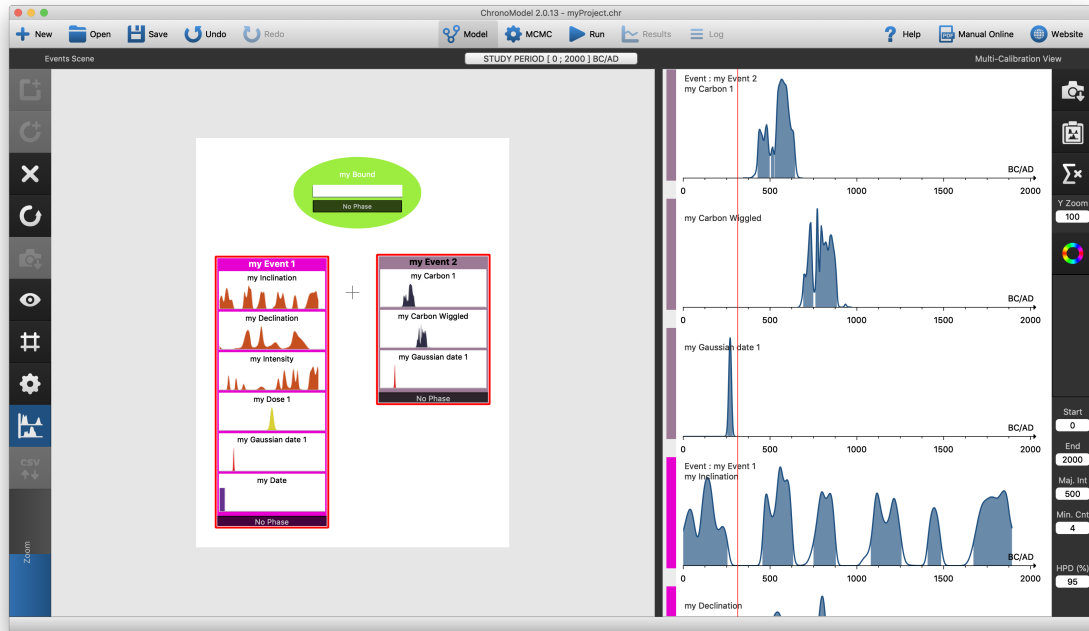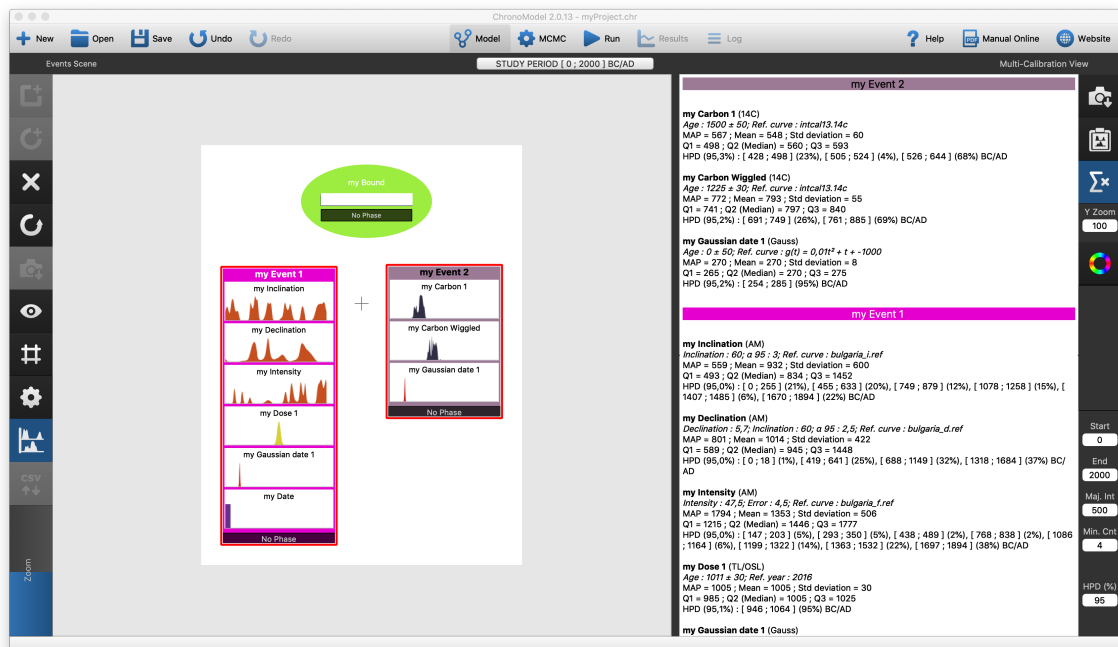In the main window in figure 16, you have on the left is the Events Scene panel and on the right the Phases Scene panel which is visible when the property button and the multi-calibration button are not selected.

For simplicity, the Phases scene tools are identical to those of the Events scene.

5.1   Creating a Phase (eventually with maximal duration)

To create a Phase, click on the ⊡ button on the right-hand side of the panel. This action will open a new dialog box presented in Figure 46.
This dialog box asks for the name and the color given to the Phase and its maximum duration. By default, the duration of the Phase is unknown. If prior information about the maximum duration is available, it can be included in the model by changing the rolling menu Max duration to Known . Then you can set the Max duration value , see Figure 47.

When a prior duration on the max duration of a Phase is set, it appears a white box with the information at the bottom of the Phase item, after the Event's list. An example is given in figure 48.
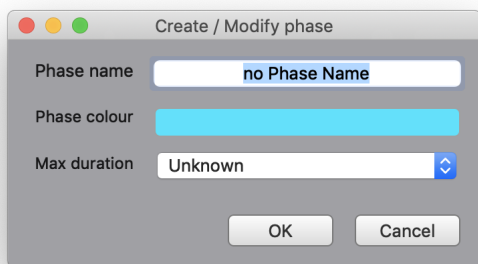
Figure 46 – Basic dialog box for the Phase
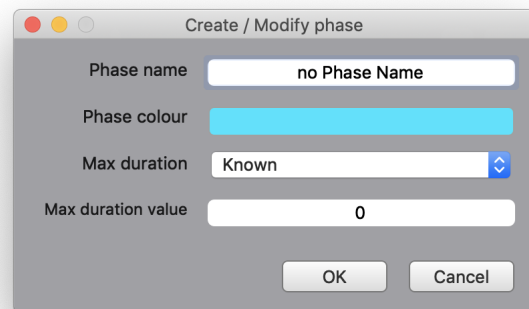
Figure 47 – Dialog box to include prior information about the maximum duration of the Phase

5.2   Modifying a Phase

To modify a Phase, double-click on it and the dialog box presented in Figure 46 will be reopened.

Figure 48 – Example of a Phase with prior duration

5.3   Deleting a Phase

To delete a Phase, select the Phase to be deleted by clicking on it and then click on the ❌ button on the left-hand side. The Phase cannot not be restored. The only way is to use the undo button ↺ Undo on the main menu.

5.4   Including Events or Bounds into the Phases

Events can be included in a Phase. Select one or several Events or Bounds from the Events scene and then click ⬈ on the top left of the Phase item. The Figure 49 presents the inclusion of an Event in a Phase.
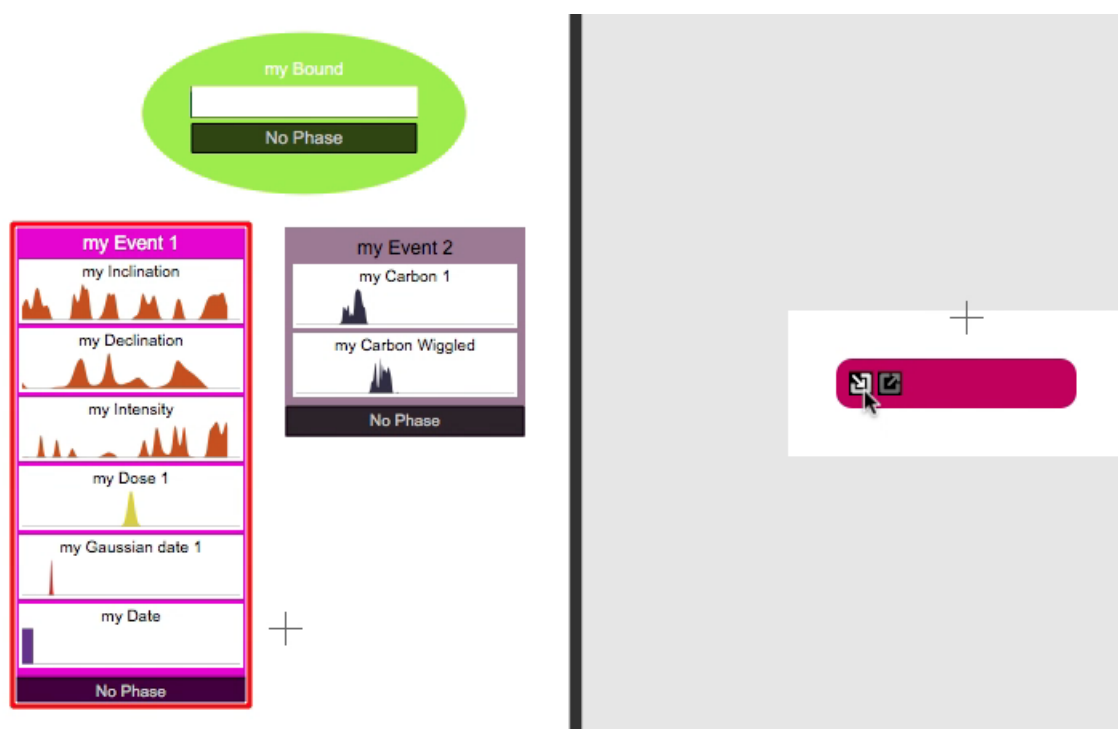
Figure 49 – Including an Event in a Phase

As a result, the color of the Phase appears on the bottom of the Event (or the

Bound) item, and the name and the color of the Event (or the Bound) appear at the bottom part of the Phase item.

Of course, several Events or Bounds may be included in a same Phase. An Event or a Bound may also belong to several Phases. Now when you select an Event, it appears highlighted in one or several Phases it belongs to.

5.5   Removing Events or Bounds from the Phases

To remove an element from a Phase, select this element from the Events scene, and click on 🖇 button in the Phase from which this element should be removed. Once the element is removed from a Phase, its name does not appear any more in the Phase item and the Phase color does not appear any longer in the Event item.
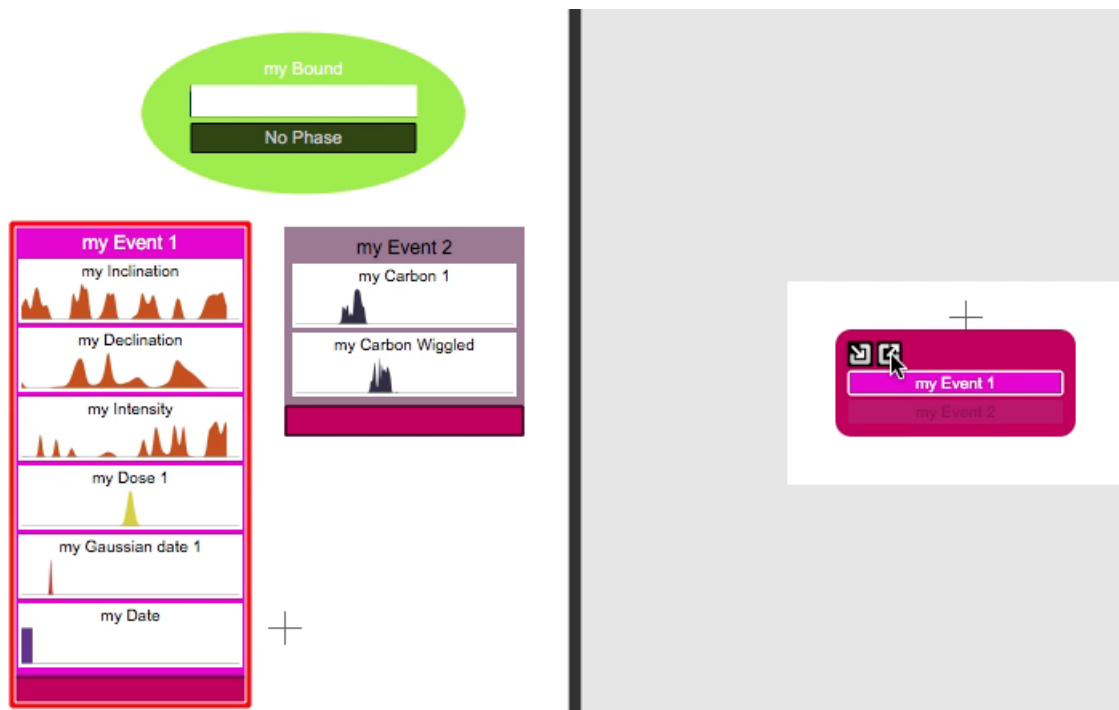
Figure 50 – Excluding Events from a Phase

The buttons 🖇 and 🖇 appear only when the pointer passes over the Phase item.

5.6   Order constraints between the Phases

A succession constraint may relate two Phases.

5.6.1   Creating order constraints

In the same way as for the Events, select the "oldest" Phase. Press and keep pressing the Alt key from your keyboard and move the arrow up to the "youngest" Phase. If the solution is possible you see a green dashed line with "OK" as a label, and click on it. Now, you can release the Alt key and a black arrow should be seen between both Phases heading from the older Phase to the younger one. Figure 51 displays an example. If the solution is not possible (Figure 52), just like in the Events scene, the arrow become a red dashed line with a cross.
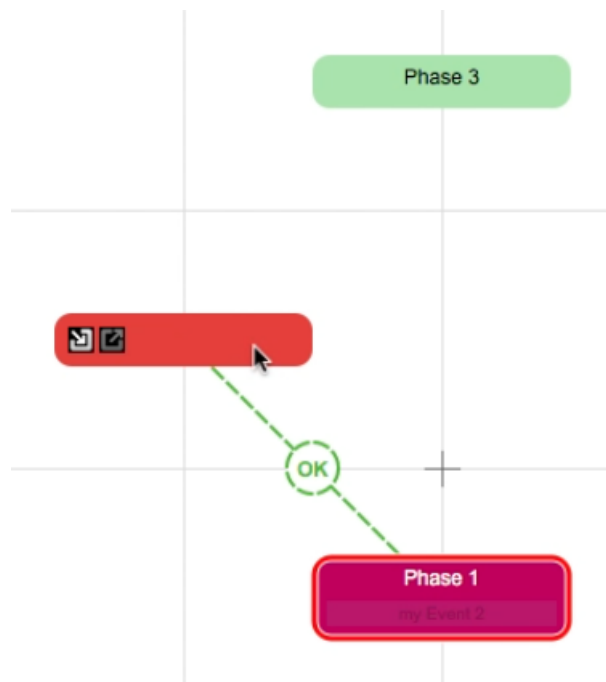
Figure 51 – Possible constraint between two Phases
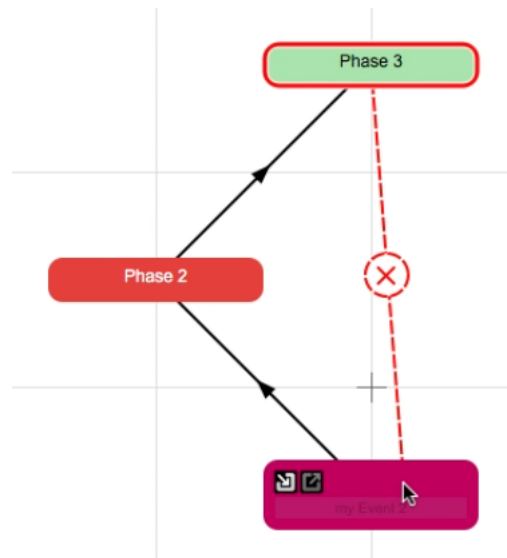
Figure 52 – Impossible constraint between two Phases

Control of the constraints occurs while drawing, by checking the logic of the diagram. Complete control of the constraints with the Events is done on the initialization of the MCMC.

Remark: Order constraints can be put even when the Phase items are empty.

5.6.2   Hiatus between two Phases

In ChronoModel, a hiatus expresses the minimum time elapsed between two Phases. By default, the hiatus between these Phases is unknown. However, if prior information about the hiatus is available, it can be included in the model.

When the pointer passes over an order constraint, the arrow becomes red with a question mark in the center. Click on the question mark to access to the order constraint property and a dialog box appears.

If you want to set a minimal value for the hiatus, choose "Known" in the Min hiatus and then you can access to the minimal value setting. Click OK to finish.

5.6.3   Removing order constraints

To delete a constraint, go to the constraint property and in the dialog box click on Delete constraint .
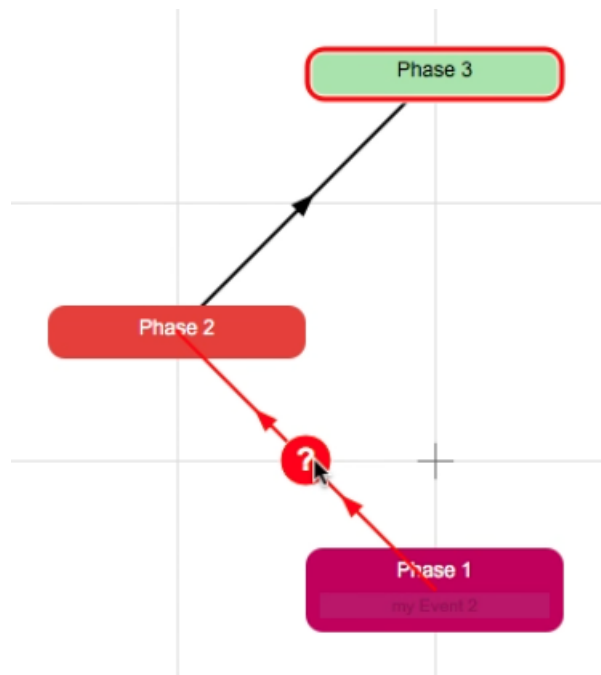
Figure 53 – Constraint property access
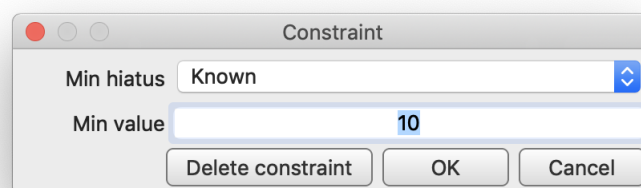
Figure 54 – Setting minimal value for hiatus
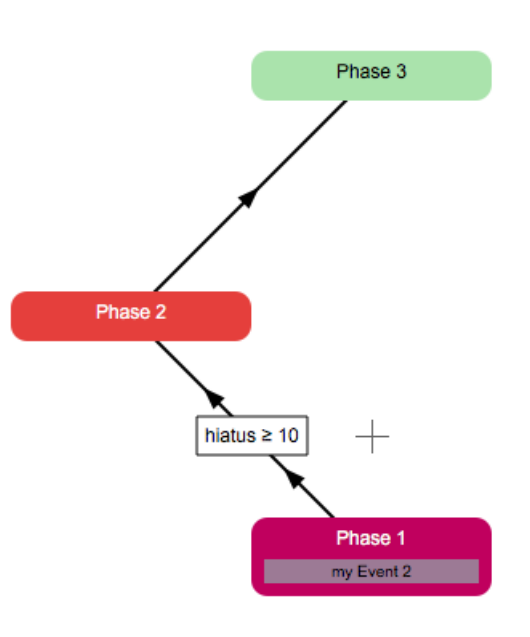
Figure 55 – Order constraint with a hiatus indication
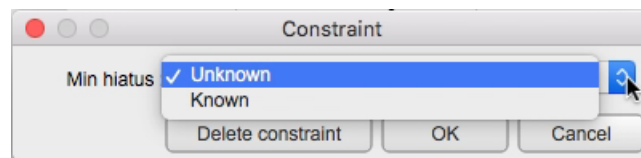
Figure 56 – Dialog box to modify a hiatus between two Phases

5.7   Using the grid to align Phase items

By default, the Phases scene is white. A grid may be added using the ⊞ button situated on the right-hand side.

This shows a grey grid with a "magnetic effect", to help you to align Phases.

5.8   Phase overview

The Phases scene may also be seen from an overview using the ⊙ button situated on the right-hand side of the window.

5.9   Export image of the Phases scene

The image of the Phases scene can be saved by clicking on the ⌾ button placed on the right-hand side of the window. You can save it either in PNG, JPG, BMP format or in SVG (Scalable Vector Graphics) format. You will need to name the image and to choose the directory in which to save the image.

6   MCMC

In this section, we do not explain the MCMC process. You will only find how and where to change the settings. For further information consult the references Lanos and Philippe (2017, 2018)

The button ⚙ MCMC allows you to change all the parameters used in the MCMC process.
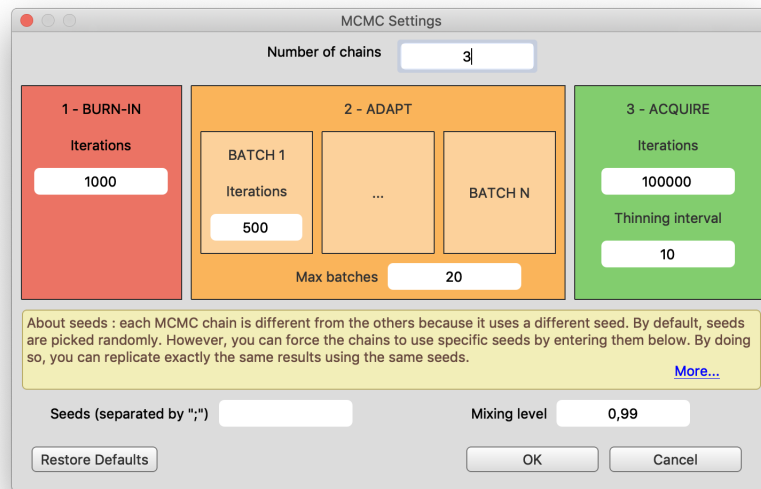
Figure 57 – MCMC parameters

The button [Restore Defaults] resets all the parameters to the default values:

Number of chains = 3

BURN-IN: Iterations = 1000

ADAPTING: BATCH Iterations = 500

ADAPTING: Max batches = 20

ACQUIRING: Iterations =100000

ACQUIRING: Thinning interval = 10

Seeds = blank

Mixing level = 0.99

7 Run

To launch an MCMC process on your model, just click on the button ![Run]. There will be as many MCMC process cycles as requested chains. A MCMC process cycle is composed of :

Initialization can be very fast, may be you will never see some of these steps.

- Initializing Phases Gaps. . .
- Initializing Phases Durations. . .
- Initializing Events . . .
- Initializing Variances. . .
- Initializing Phases. . .

Burn-in to forget the initialization.

Adapting to tune the random walker.

Running - acquisition the real sampling state, often can be the slower

Usually the acquisition process is the longest one.

During the process you can stop by clicking ![Cancel]
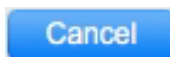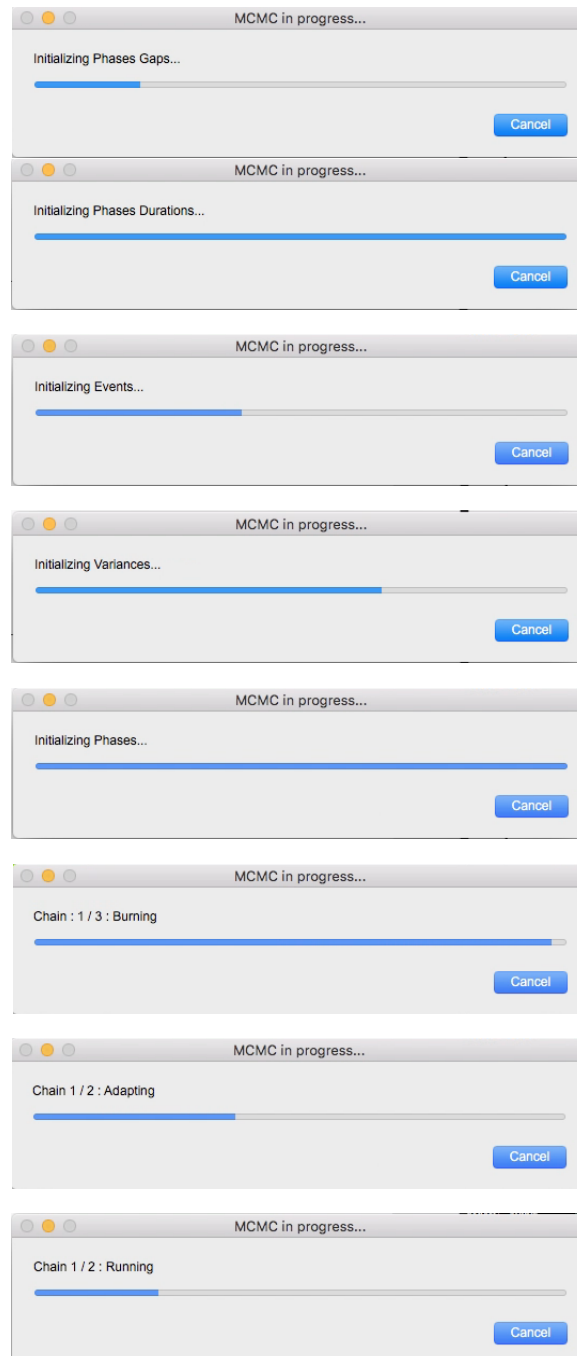
Figure 58 – Run windows

At the end of the MCMC process, ChronoModel makes post-treatments to compute the results and the "results" window is immediately displayed with the posterior distributions.
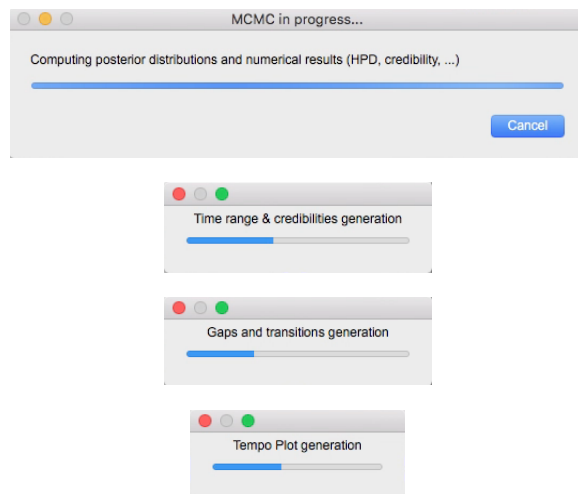
Figure 59 – Post-treatment computing windows

8   Results

The "Results" window appears just after all the MCMC sampling cycles are completed
and the button [Results] is enabled.

If there are Phases in your model, the results are directly shown at the Phase level,
otherwise at the Event level.

8.1   Browsing the results and graphical options

In the results window, on the right-hand side, there is the Main Results panel, to
manage the view of the model's results. At the top part, you choose which level
(Events, Phases, Tempo) you want to see.

In the middle part, there are the graphical options, to adjust all drawings.

At the bottom part, this gives the way to navigate over the pages and the saving
tools.

In each part, there are tabs providing new menus.

When the pointer passes over a graph, a tip and a red line indicate the position
on the graph coordinates.
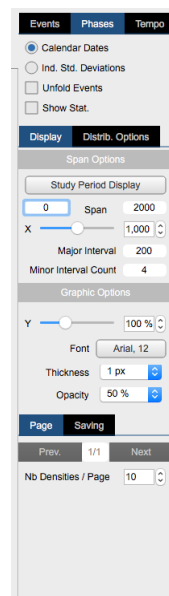
Figure 60 – Main Results panel

On the top left, there are several tabs allowing access to the different types of
plots.

Posterior Distrib.   shows the marginal posterior distributions.

History Plot   shows the values sampled during the MCMC process.
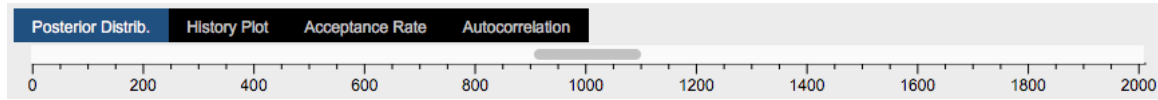
Figure 61 – Type of curves tabs and ruler

Acceptance Rate shows the evolution of the acceptance rate during the MCMC
process.

Autocorrelation shows the correlation over the acquiring Phase of the MCMC
process.

The number of tabs depends on the tab chosen in the Main Results Options panel.
Under plot tabs, there is a ruler to slide on the X axis. The values are reported in
the Main Results Options panel (Span).

8.2 Browsing results

The upper part of the main results panel manages which results you want to see.
There are three possibilities : **Events** , **Phases** or **Tempo** .

If there is no Phase in your model, only one tab with **Events** is enabled.

8.2.1 Events Tab

When you click on the **Events** tab, two radio buttons display either the **Calendar
Dates** θ_i, or the **Ind. Std. Deviations** $\sqrt{v_i}$ of all the dates of the Event graph. There
is also a checkbox **Unfold Data** to display all the Data of the Events.

If you see the **Posterior Distrib.** type of curve and if this checkbox is ticked, two
more checkboxes appear to show on the Data results the **Individual Calib. Dates**
existing without modeling and the **Wiggle shifted** showing the wiggle correction.

The Data results have the same color as their Event, but the background is white.

The **Individual Calib. Dates** is a grey line. And the **Wiggle shifted** is a grey
dashed line.

A last checkbox **Show Stat.** shows the statistical results in a box on the right of the
graphs.

8.2.2 Phases Tab

The only difference between **Phases** tab and the **Events** tab is that one more
checkbox **Unfold Events** appears, proposing to unfold all the Events belonging to
the Phases and, after, to unfold the Data belonging to these Events.
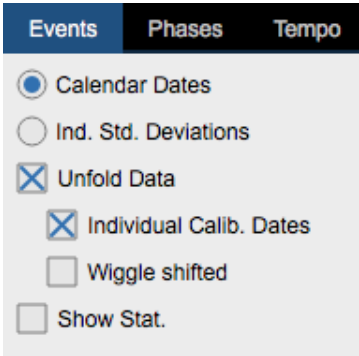
Figure 62 – Events tabs
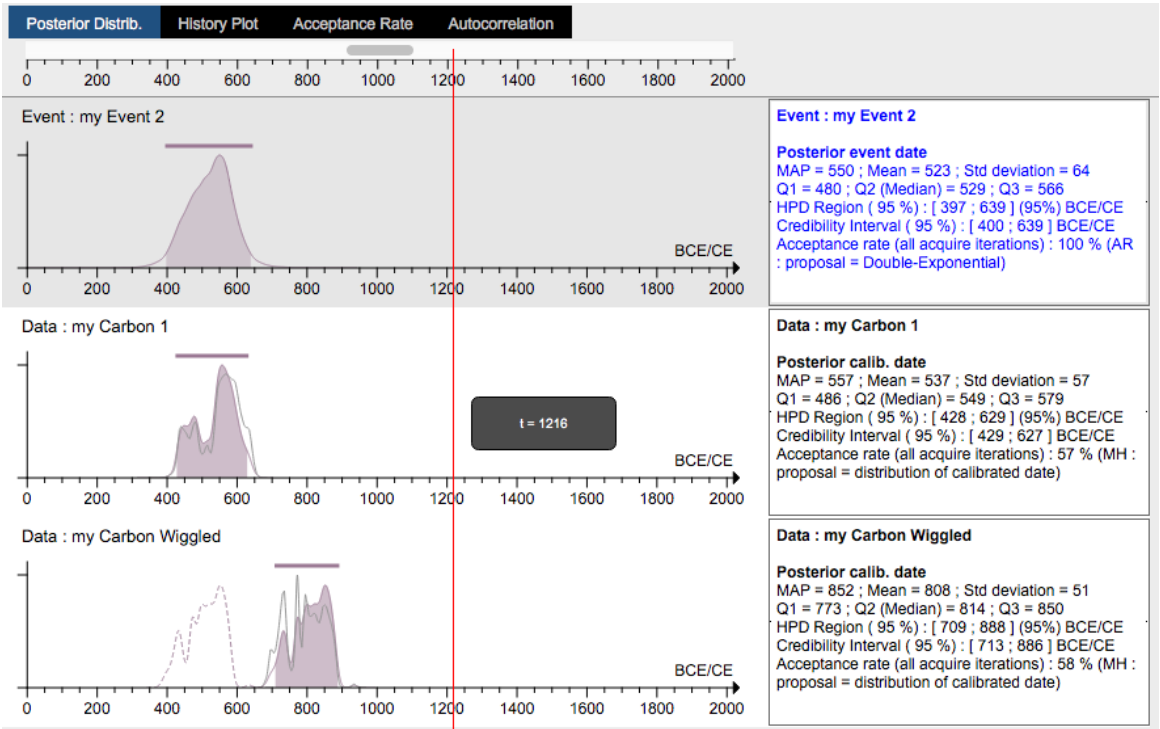
Figure 63 – Events and Data drawings
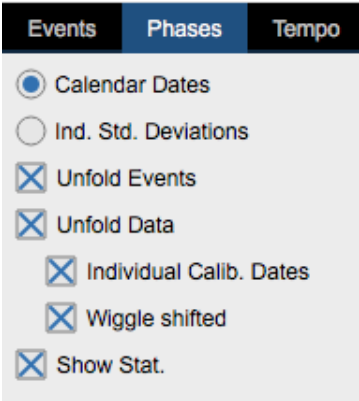
Figure 64 – Phases tabs

8.2.3   Tempo Tab

This is a new tab in ChronoModel. With this tab you can obtain post-treatment results for each Phase.

There are three radio buttons for three different computations.

- Phase Duration gives the difference between the end and the beginning of a Phase.

- Phase Tempo gives the mean number of Event dates occurring before a given time (see Dye (2016)). When this is ticked you can add to the curve the credibility envelope Tempo Cred and/or the Gaussian error envelope Tempo Error .

- Phase Activity gives the mean number of Event dates per time unit.
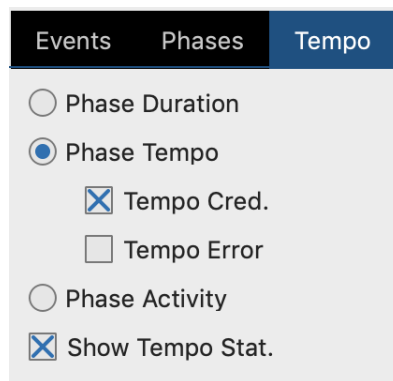
Figure 65 – Tempo results

And the checkbox Show Tempo Stat. shows the numerical results.

8.3   Graphical Options

In the middle part of the Main Results panel, there are two tabs Display and Distrib. Options . If you choose to see the Tempo , only the Display tab appears.

8.3.1   Display Tab

This box is composed of two parts.

The Span Options part manages the axis scales.

If you are viewing the Posterior Distrib. of a Calendar Dates , a button called Study Period Display appears to reset the period viewed on the study period defined for the model, in the model windows.

If you are viewing the Posterior Distrib. of Ind. Std. Deviations , the Fit Display button adjusts the axis in order to see the "optimal" curve.

Two boxes on both sides of the label Span allow you to set by yourself the start and the end of the axis.

Beside the X label, a slider and a spinbox manage the zoom on the axis.

The following two boxes Major Interval and Minor Interval Count are used in the same way as in the calibration process window (see section 4.3.6).

The Graphic Options part manages the drawing of the curves.

Beside the X label a slider and a spinbox manage the zoom on the axis.

The button near the label Font allows you to change the font used for the drawings.

The spinbox near the label Thickness defines the size of all lines used for the curves.

The spinbox near the label Opacity modifies the transparency of solid colors. 0% makes the solid part of the curve disappear and 100% cancels the transparency.
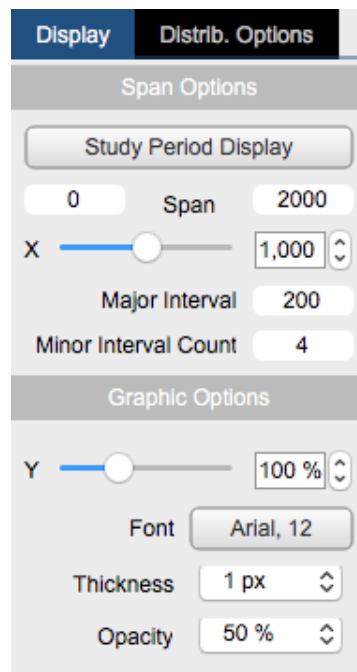
Figure 66 – Display Tab

8.3.2   Distrib. Options Tab

This box is also in two parts.

The MCMC Chains part manages the chain drawing. Check the chain you want to examine.

With the tab Posterior Distrib. you can see the Chain Concatenation checkbox which allows you to mix all the acquired iterations in order to carry out the global statistical calculations.

The Density Options part manages the post-treatment. This is enabled only with the tab Posterior Distrib. .

The checkbox Show Confidence Bar activates the drawing of the time range bar on the Phases drawing, and the credibility bar on the Events and Data graphs.
The Confidence Level box sets the threshold for the computation of the HPD region, the Phase time range, and the credibility interval for the Event and the Data distributions.
The Grid Length box sets the length of the FFT smoothing.
The Bandwidth Const. sets the bandwidth value used in the smoothing process of the distribution curves.

Figure 67 – Distrib. Options Tab

8.4   Page and saving tools

There are two tabs. Page used to navigate over the page and Saving to export the graphs, the MCMC chains and the statistics (see figure 68).

8.4.1   Page

This box is also in two parts.
There are two buttons Prev. and Next on both sides of the label indicating the number of the current page and the number of the total page. The Prev. button

change the current page to the previous page and the $\boxed{\text{Next}}$ button changes the current page to the next page.

With the spinbox $\boxed{\text{Nb Densities/Page}}$, you can set the number of curves per page.
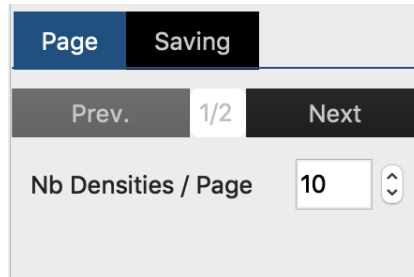
Figure 68 – Distrib. Options Tab

8.4.2 Saving

The box has either two buttons (see Figure 69) or four buttons (see Figure 70), depending on whether you have selected a graph or not. To select one or several graphs on a page, just click on them and a grey overlay with the $\boxed{\text{Selected}}$ label comes over the picture.
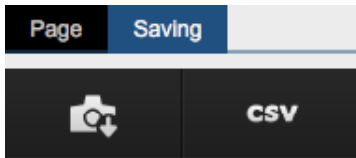
Figure 69 – Saving all the page
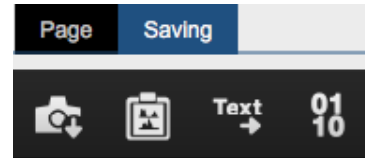
Figure 70 – Saving Individual Curves

With the two-button configuration (Figure 69)

- ![icon] Save all the graphs present on the current page. When clicking, a dialog box appears, requesting the name of the new image file, see section 3.2.5 to set the exportation format.

- **CSV** Save all the results in CSV files. By clicking, a dialog box appears, requesting the name of the folder in which to save the files. In this folder, ChronoModel saves:

  `Chain_all_Phases.csv` a file of the traces of each Phase, a file with the traces of all the Phases,

  `Chain_all_Events.csv` a file with the traces of all the Events, including the dating Data,

Three HTML files (use an internet navigator to open them):

Log_MCMC_Initialization.htm,

Log_Model_Description.htm,

Log_Posterior_Distrib_Stats.htm

These three files contain the replications of the contents of the three tabs Model Description , MCMC Initialization and Posterior Distrib. Stats which are in the ≡ Log window.

Synthetic_Stats_Table.csv is a file grouping the statistical results : MAP, mean, quartiles Q1, Q2, Q3, Credibility Interval and HPD region.

To choose the CSV format, see section 3.2.4.

When you click on a graph, an overlay comes with the text "Selected"; It means that you have selected the graph. You can select several graphs on a page. If there is a
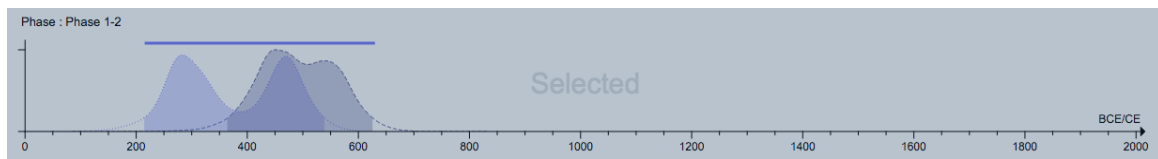
Figure 71 – Example of selected drawing with overlay

drawing selected, the Saving shows four buttons

- 📷 Save all selected drawings present on the page in a single file. A save dialog box appears asking to choose the folder name and the type of file.

- 🖼 Copy all the selected graphs present on the page in the clipboard.

- Text→ Copy all the statistics of each selected item in the clipboard.

- 01 10 Export a CSV file to be able to use the points of the graph with another piece of software. For each item you will have a save dialog box. In the case of the type History Plot , you will have one more question: "Do you want the entire trace from the start of the process or only the acquisition part?".

8.5   Marginal Posterior Distributions

In ChronoModel, the MCMC results are displayed as marginal posterior densities on the time scale (X axis).
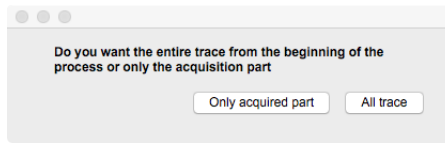
Figure 72 – Example of Posterior Distribution drawing for an Event item

8.5.1   Graphs for Data, Events, Phases

The posterior densities are estimated by using a FFTW process with controllable settings in `Distrib. Options` ≫ `Density Options` (see section 8.3.2).

- For the Data: If the item is a Data result, the distribution curve obtained from the FFTW process is displayed with the same color as the parent Event. Under it, the solid area is limited by the HPD region. If you have ticked the `Unfold Data` ≫ `Individual Calib. Date`, the individual Calibration distribution without model constraints (see section 4.3.6) is displayed in grey outline.
  If you have ticked the `Unfold Data` ≫ `Wiggle shifted` (see Figure 62 and Figure 64, one more curve is displayed in a grey dashed line.
  If you checked `Density Options` ≫ `Show confidence Bar` (see section 8.3.2), the credibility interval is plotted as a horizontal bar above the curves.
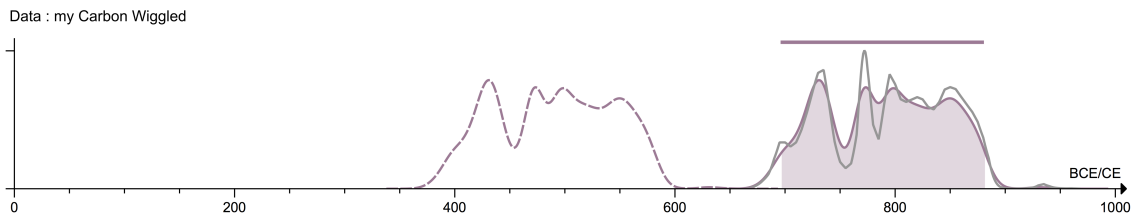
Figure 73 – Example of Posterior Distribution graph for a Data item

- For the Event: In the same way as for the Data curve, the Event date's marginal posterior distribution is displayed with a continuous line, and the HPD region is a solid area under the curve.
  Like the Data Credibility interval, the credibility interval for the Event date is displayed in the form of a bar.
  The color of the graph is the color of the Event item in the Events Scene.

- For the Phase: If the item is a Phase, you can see the beginning (with doted line) and the end posterior distributions (with dashed line) on the same graph. Under both curves, the solid area is limited by the HPD region.
  At the top of the graph, there is the "Time Phase Range" bar obtained from
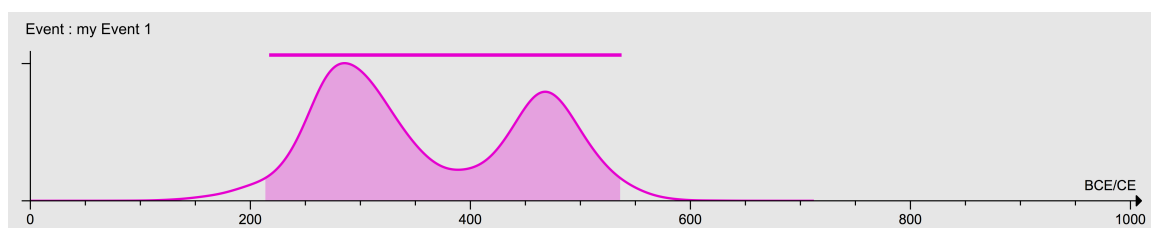
Figure 74 – Example of a Posterior Distribution graph for an Event item

the calculus of the same name.

This bar is shown if you ticked the Density Options ⟩ Show confidence Bar (see section 8.3.2)

The color of the graph is the color of the Phase item in the Phases Scene.
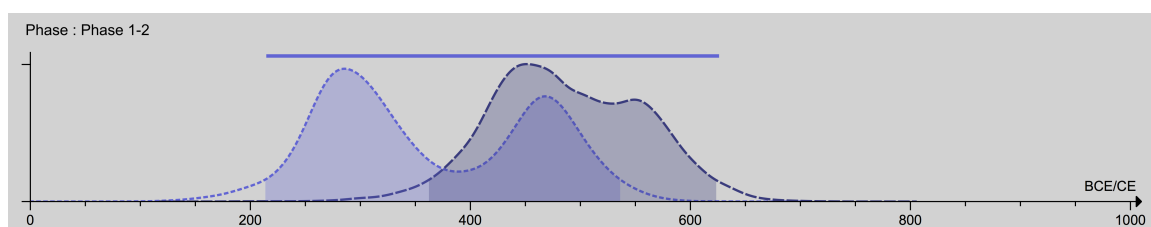
Figure 75 – Example of a Posterior Distribution drawing for a Phase item

8.5.2   Statistics view

In the Main Results Option, click on Show Stat. or Show Tempo Stat. . A box appears on the right of each graph, with the classical statistical parameters which summarize the posterior density with the Posterior Distrib. .

This summary includes : MAP (posterior mode), Mean, Std Deviation, quartiles Q1, Q2 (Median), Q3, HPD Region and Credibility Interval at a given confidence level in the Distrib. Options ⟩ Density Options ⟩ Confidence Level (%)

8.5.3   History plot

The tab History Plot shows the values sampled during the MCMC process. This is a good view to check whether the model has reached a stationary state. This plot is called the trace. At the top, the ruler recalls the different steps of the MCMC process: in red the burn-in process, in orange the adapting process and in green the acquisition process. On the Phase graph, there are two traces, one for the beginning and one for the end.

The green lines are the values of the quartiles Q1 and Q3 and the red line is the value of Q2. These quartiles are computed with the acquired part which corresponds to the concatenation of all the chains.
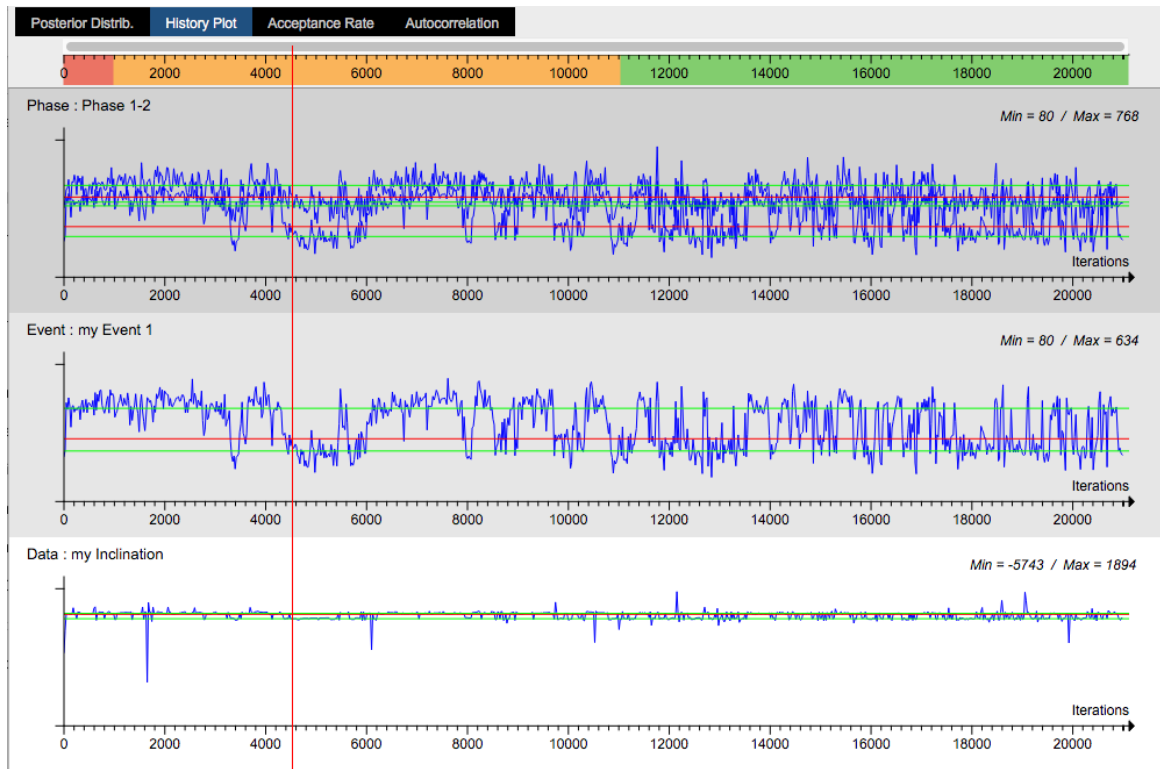
Figure 76 – Example of traces for Phase, Event and Data

8.5.4   Acceptance rate

The acceptance rate is available only for Data and for Events. If you choose the Method "MH : Proposal = adapt. Gaussian Random Walk" in the Event's properties, then the expected theoretical value for the acceptance rate is 44%. This value is represented by a red dashed line on the history plot.
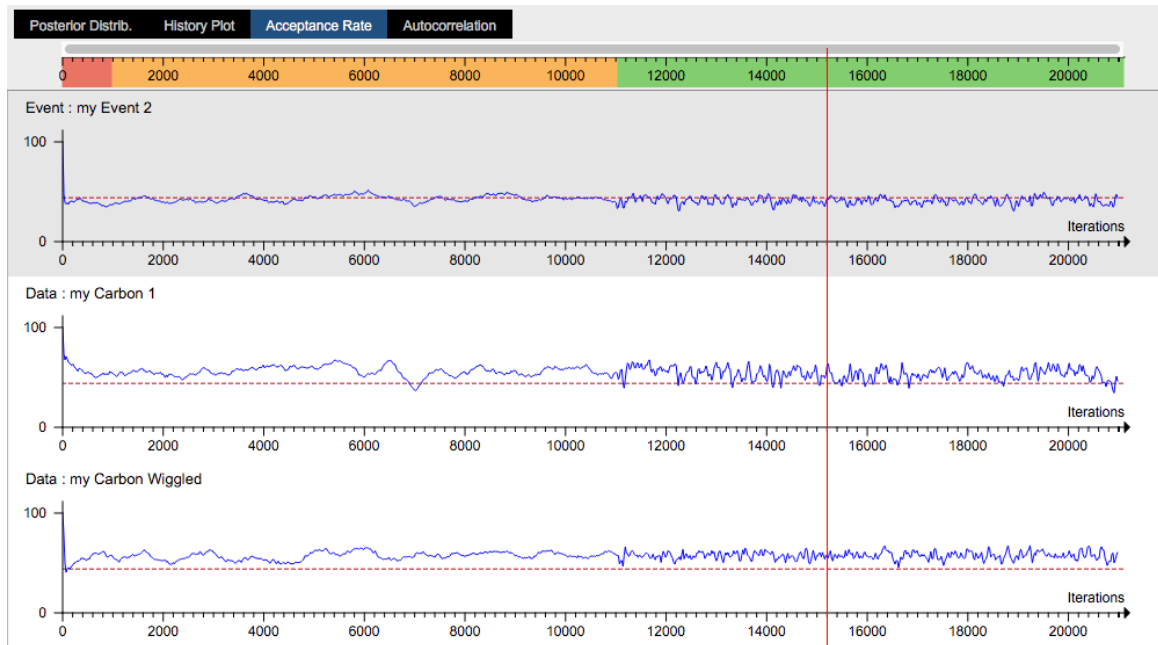
Figure 77 – Example of Acceptance rate for Event and Data

8.5.5   Autocorrelation

The Y axis is always between 0 and 40.

The red dashed line has the value of 0. The autocorrelation must quickly reach 0, the best would be from the 1st iteration.
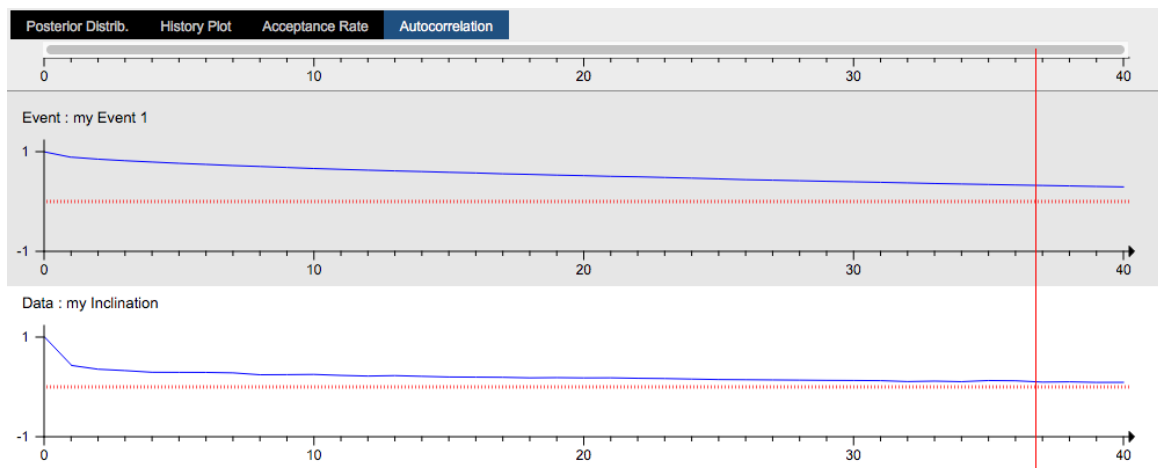
Figure 78 – Example of an autocorrelation plot for Event and Data

8.6   Tempo

The Tempo allows to see post-treatments on the Phases. This tab is enabled only
if at least one Phase is defined in your model. There is only one type of curve
 Posterior Distrib. .

8.6.1   Phase Duration

The Duration density gives the probability density of the difference between the end
and the beginning of a Phase.
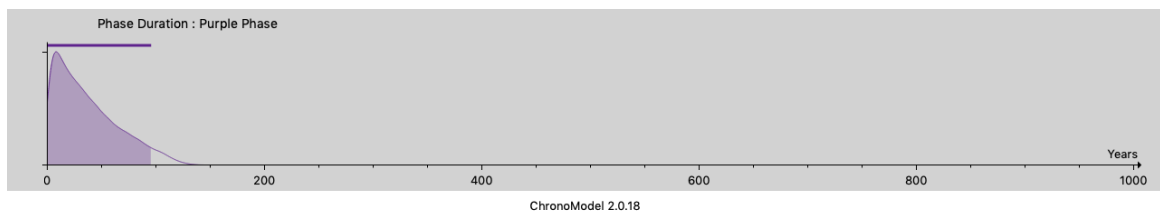
Figure 79 – Example of Phase duration density

8.6.2   Tempo-Plot

The Tempo-Plot gives the mean number of Event dates occurring before a given
time, with the credibility envelope Tempo Cred. and/or the Gaussian error envelope
 Tempo Error .
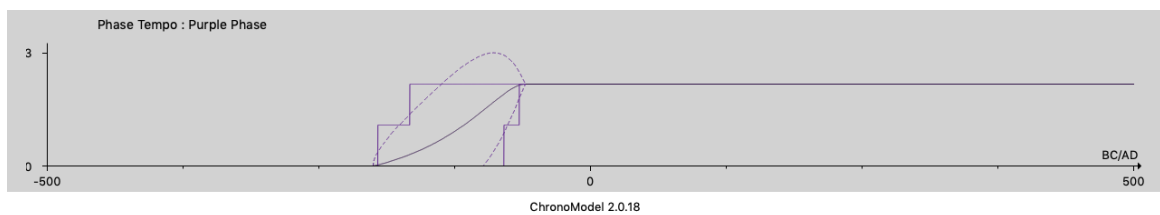
Figure 80 – Example of Phase tempo plot

8.6.3 Activity Curve

The Activity Curve gives the mean number of Event dates per time unit. The error envelope on this curve is not yet available.
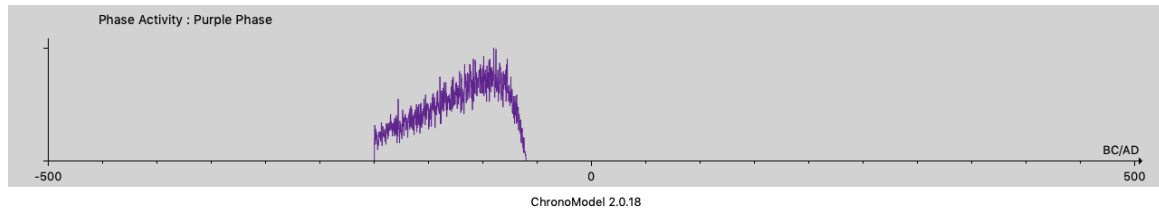
Figure 81 – Example of Phase activity plot

8.6.4 Tempo Statistics

When Show Tempo Stat. is clicked, a box appears on the right of each Tempo graph with the classical statistics information, but here the statistics are on the Phase duration only, and are neither on the Tempo plot nor on the activity plot.
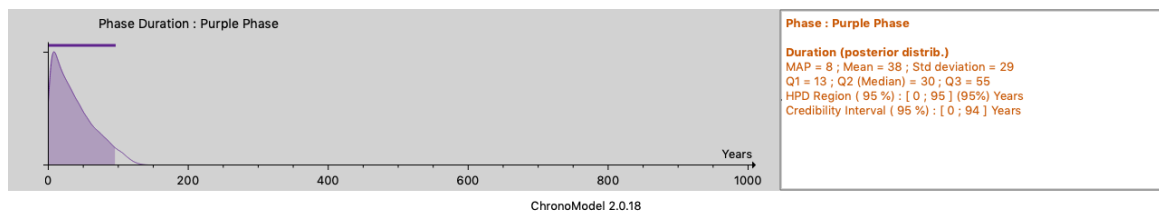
Figure 82 – Example of Phase duration density with stats info

9   Log

On the [≡ Log] tab, a list of summaries is displayed.

Under Model Description is a summary of the model structure along with the type of measurement, age, standard deviation, reference curve for the calibration process, MCMC method, stratigraphic constraints, and so on.

Under MCMC Initialization is the list of the initial values used in the MCMC process and for each chain. This text is created at the first step of MCMC in the Initialization process. The information stacked on this panel is produced with the application settings which are used at the beginning of the run. So, the date format and the decimal separator cannot be changed after the run process.

Under Posterior Distrib. Stats are all the statistical results according for all the posterior distributions.

   If you remember when you saved all the results in CSV files (see 69, these three tabs are saved in a html format. Indeed, this is useful to read results without having to open ChronoModel.

9.1   Model description

The first line recalls the study period set in the model. A color is defined by item type: Data in black, Events in blue, Bounds in red and Phases in orange. The main organization is: The description of each Event with the description of each of the Data included.
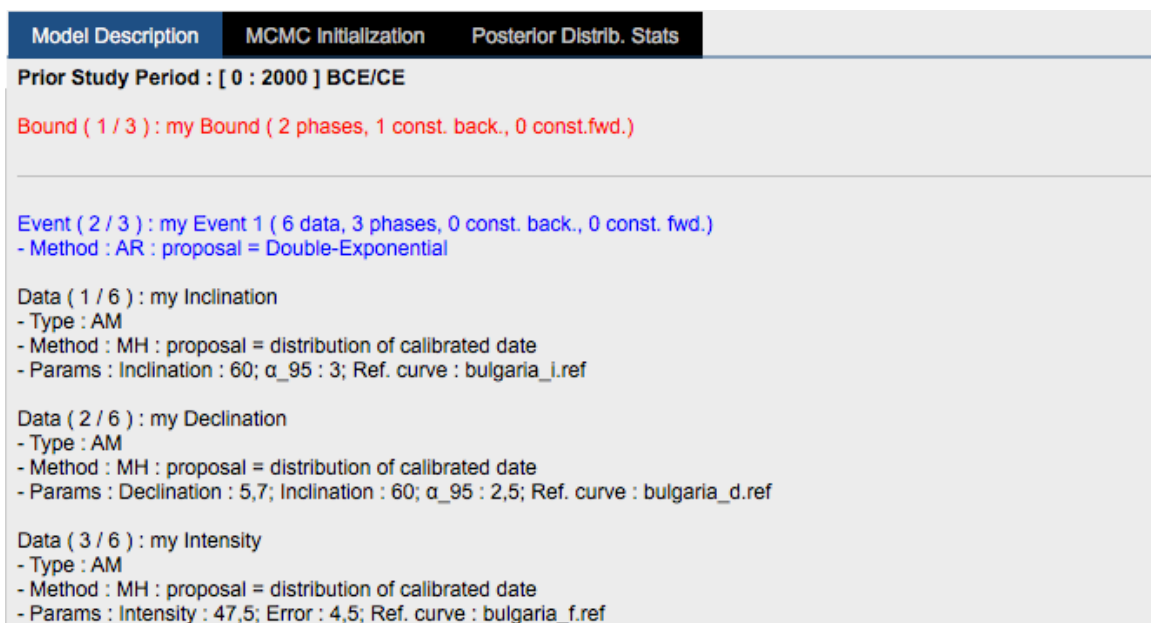
Figure 83 – Events and Bounds description

The description of each Phase with a reminder of the name of the Event included. The description of the constraint between Phases named "Succession"

Figure 84 – Phases description

9.2   MCMC initialization

These comments are recorded in an internal memory along the way. It means that the format date value cannot be changed after the MCMC process. The first line is the date and the hour at which the MCMC process started. This is followed by the seed of each MCMC cycle. A text indicates the list of the seeds used in the MCMC Settings to redo the same calculus. Here in the example:

List of used chains seeds (to be copied for re-use in MCMC Settings) : 703;832;32

So, if you want to redo the same process set 703;832;32

After the MCMC process initialization, for each chain there are the values of all the parameters: the Bounds in red, the Events in blue, with their Data in black and at the end the Phases and the order constraints.

The header is a reminder of the model's sampling parameters, with the seed value of each chain.

Start mercredi 20 juin 2018 ->>> 19:16:19.587

Seed : 703

Seed : 832

Seed : 32
List of used chains seeds (to be copied for re-use in MCMC Settings) : 703;832;32
Model computed
finish at 19:16:39.011
time elapsed 0 h 0 m 19 s 424 ms

Chain 1
Seed 703
Number of burning iterations : 1000
Number of batches : 20 / 20
Number of iterations per batches : 500
Number of running iterations : 100000
Thinning Interval : 10
Total iterations : 111000
Mixing level : 0.99

Chain 2
Seed 832
Number of burning iterations : 1000
Number of batches : 20 / 20
Number of iterations per batches : 500
Number of running iterations : 100000
Thinning Interval : 10
Total iterations : 111000
Mixing level : 0.99

Figure 85 – Seeds initialization

INIT CHAIN 1

Events Initialisation (with their data)

Bound (1 / 3) : my Bound
- Theta : 1000 BCE/CE
- Sigma_MH on Theta : 0

Event (2 / 3) : my Event 1
- Theta : 108 BCE/CE
- Sigma_MH on Theta : 51
- S02 : 2578

Data (1 / 6) : my Inclination
- ti : -5982 BCE/CE
- Sigma_i : 6090
- Sigma_MH on Sigma_i : 1

Figure 86 – Events initialization

Phases Initialisation

Phase (1 / 5) : Main Phase
- Alpha : 108 BCE/CE
- Beta : 1000 BCE/CE
- Tau : 0

Phase (2 / 5) : Phase 3
- Alpha : 1000 BCE/CE
- Beta : 1000 BCE/CE
- Tau : 0

Phase (3 / 5) : Phase 2
- Alpha : 243 BCE/CE
- Beta : 243 BCE/CE
- Tau : 0

Phase (4 / 5) : Phase 1-2
- Alpha : 108 BCE/CE
- Beta : 243 BCE/CE
- Tau : 200

Phase (5 / 5) : Phase 1
- Alpha : 108 BCE/CE
- Beta : 108 BCE/CE
- Tau : 0

Phases Constraints Initialisation

Succession (1 / 2) : from Phase 1 to Phase 2
- Gamma : 10

Figure 87 – Phases initialization

9.3   Posterior Distrib. Stats

On this tab you find all the classical statistics summaries for each item of your model. The date format is defined in the Application Settings ⟫ Time Scale and the threshold for HPD region and credibility is set in the [⟍ Results] Density Options ⟫ Confidence Level (%). Unlike the Model Description , if you change the threshold or the date format, all the results are recalculated. The list starts with the Phases results in orange, next Phases constraints (named Succession) in green and next Bounds results and finishes with the Events results including Data and Std. Deviation results.

Model Description   **MCMC Initialization**   **Posterior Distrib. Stats**

Phase : Phase 1

Begin (posterior distrib.)
MAP = 283 ; Mean = 372 ; Std deviation = 99
Q1 = 286 ; Q2 (Median) = 353 ; Q3 = 465
HPD Region (50 %) : [259 ; 321] (28%), [445 ; 493] (22%) BCE/CE
Credibility Interval (50 %) : [229 ; 382] BCE/CE

End (posterior distrib.)
MAP = 283 ; Mean = 372 ; Std deviation = 99
Q1 = 286 ; Q2 (Median) = 353 ; Q3 = 465
HPD Region (50 %) : [259 ; 321] (28%), [445 ; 493] (22%) BCE/CE
Credibility Interval (50 %) : [229 ; 382] BCE/CE

Phase Time Range (50 %) : [229 ; 382] BCE/CE

Duration (posterior distrib.)
MAP = 0 ; Mean = 0 ; Std deviation = 0
Q1 = 0 ; Q2 (Median) = 0 ; Q3 = 0

Succession : from Phase 1 to Phase 2

Transition Range (50 %) : [267 ; 523] BCE/CE
No Gap

Figure 88 – Phases results

Bound : my Bound

Posterior bound date
MAP = 1000 ; Mean = 1000 ; Std deviation = 0
Q1 = 1000 ; Q2 (Median) = 1000 ; Q3 = 1000

Event : my Event 1

Posterior event date
MAP = 283 ; Mean = 372 ; Std deviation = 99
Q1 = 286 ; Q2 (Median) = 353 ; Q3 = 465
HPD Region (50 %) : [259 ; 321] (28%), [445 ; 493] (22%) BCE/CE
Credibility Interval (50 %) : [229 ; 382] BCE/CE
Acceptance rate (all acquire iterations) : 100 % (AR : proposal = Double-Exponential)

Data : my Inclination

Posterior calib. date
MAP = 483 ; Mean = 363 ; Std deviation = 223
Q1 = 217 ; Q2 (Median) = 463 ; Q3 = 508
HPD Region (50 %) : [194 ; 249] (14%), [444 ; 546] (35%) BCE/CE
Credibility Interval (50 %) : [448 ; 600] BCE/CE
Acceptance rate (all acquire iterations) : 5 % (MH : proposal = distribution of calibrated date)

Posterior Std. Deviation
MAP = 46 ; Mean = 109 ; Std deviation = 170
Q1 = 39 ; Q2 (Median) = 70 ; Q3 = 122
HPD Region (50 %) : [19 ; 83] (47%)
Credibility Interval (50 %) : [15 ; 78]
Acceptance rate (all acquire iterations) : 45 % (MH : proposal = adapt. Gaussian random walk)

Figure 89 – Events results

10   Citing ChronoModel

10.1   Cite ChronoModel 2.0

When writing up results arising from CM 2.0, please cite our work by giving the reference with the URL for the software:

Lanos Ph. and Dufresne Ph. (2019). Chronomodel version 2.0: Software for Chronological Modelling of Archaeological Data using Bayesian Statistics. Available from: http://www.chronomodel.com

Citing the User manual:
Lanos Ph. and Dufresne Ph. (2019). ChronoModel version 2.0: User manual. Available from: http://www.chronomodel.com

10.2   LaTeX code for BibTeX

```
@Manual{chronomodelSoftwareV20−2019 ,
    title = {Chronomodel version 2.0: Software for Chronological
    Modelling of Archaeological Data using Bayesian Statistics.},
    author = {Lanos, Philippe and Dufresne, Philippe},
    year = {2019},
    url = {http://www.chronomodel.com},
}


@Manual{chronomodelManualV20−2019 ,
    title = {ChronoModel version 2.0: User manual},
    author = {Lanos, Philippe and Dufresne, Philippe},
    year = {2019},
    url = {http://www.chronomodel.com},
}
```

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