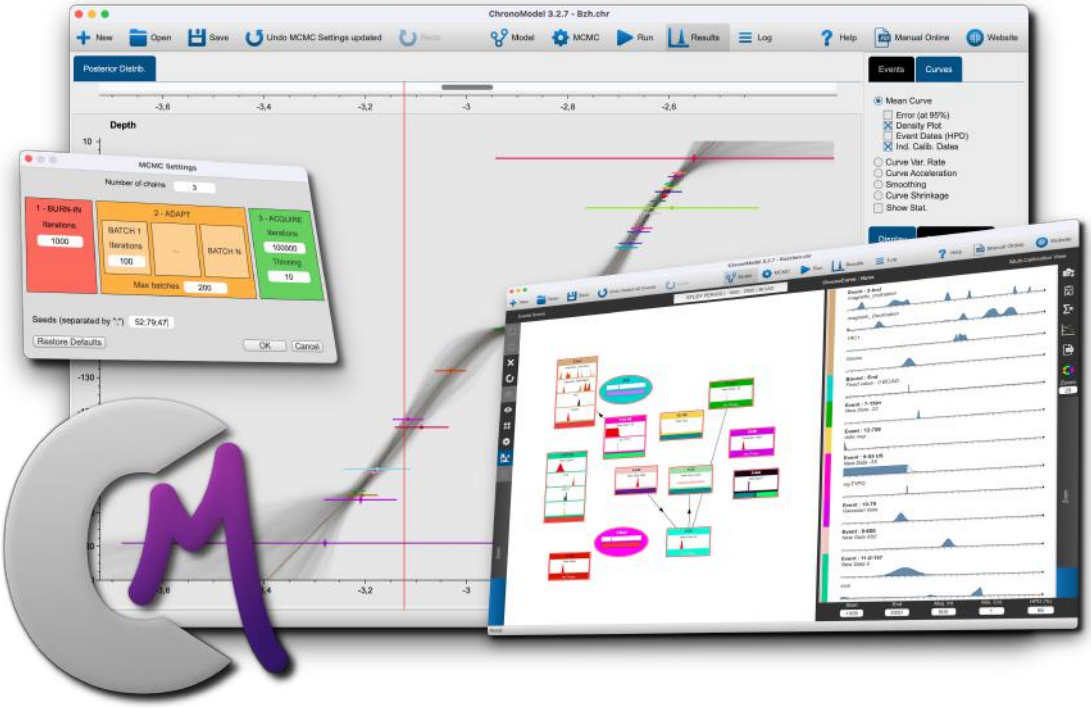
ChronoModel

version 3

User manual



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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 ChronoModel are documented in peer-reviewed literature: see Lanos and Philippe (2017), Lanos and Philippe (2018).
The present user manual provides a detailed description of how to use ChronoModel version 3. 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)
and version 2.0 Lanos and Dufresne (2019a), Lanos and Dufresne (2019b)

ChronoModel v3 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 :

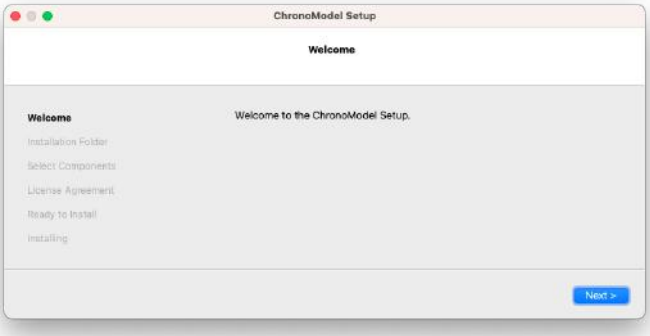
- for Mac OS X (February 2019): Supported by 12 (Monterey) and later
- for Windows 64 bits (February 2019): Supported by Windows 10

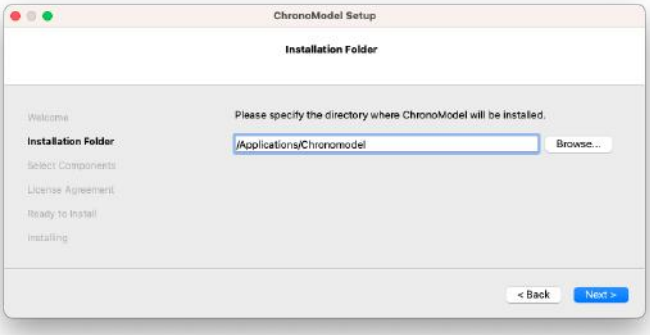
If your system does not support this version CM 3, you can download the previous versions CM 1.5 or CM 2.0 from the same Web site.
For further information on the software, send an email to : support@chronomodel.fr

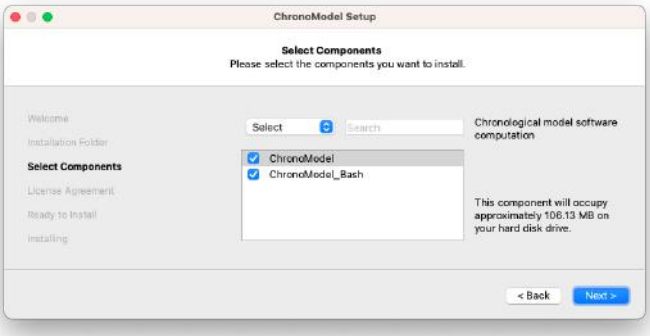
2 Installation

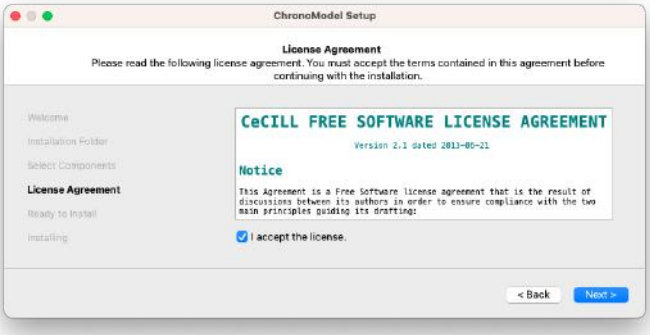
From the website (https://chronomodel.com), you can download the software adapted to your computer.

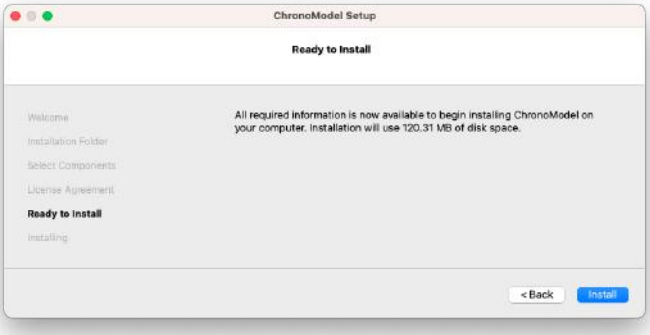
- For MAC and Windows
  Follow the application's instructions for deploying ChronoModel on your computer. You may need administrator rights.

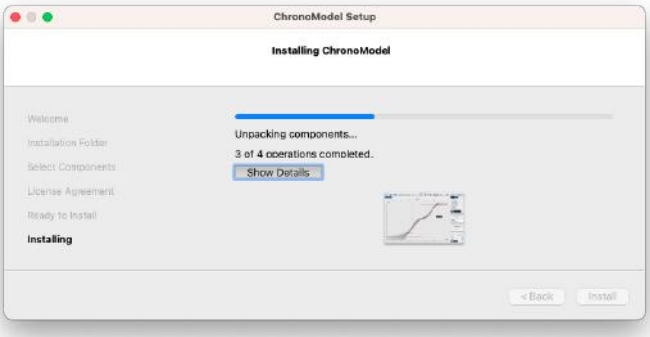


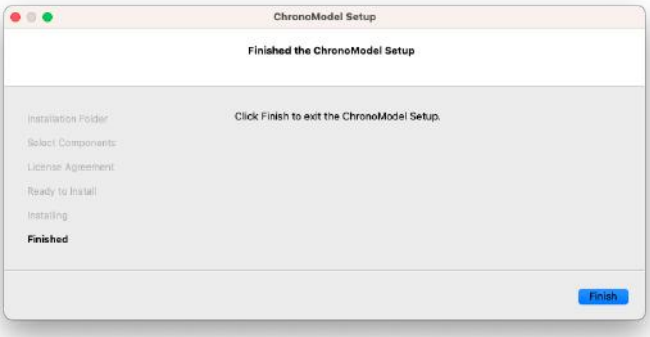












Then double-click on the package to install the software. Following the wizard window, the software is installed in the Applications directory. Once done, the

ChronoModel logo should be seen in the Applications directory.

You must have administrator rights to perform a proper installation.

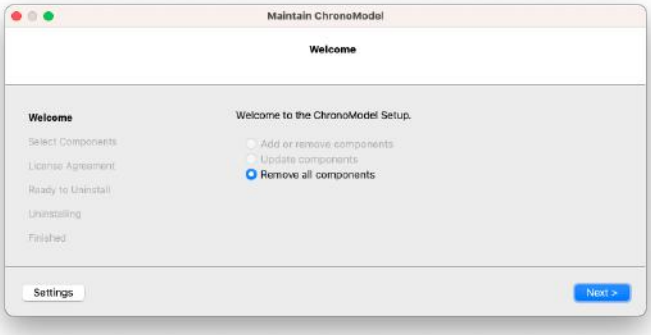
- If your system is not proposed
  You can download the source code and compile everything yourself from scratch. It is built on Qt6 (Qt is a C++ toolkit for cross-platform application development - Qt is The Qt Company Ltd product developed as an open source project (See https://www.qt.io) for more information) and uses the FFTW library (https://www.fftw.org).
  The only pre-requisite to build it yourself is to install Qt6 on your system. The project is hosted on GitHub.com. You can clone the repository by typing :

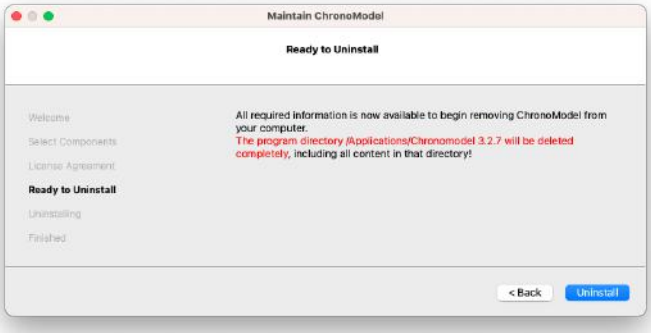
```
1 $ clone https://github.com/Chronomodel/chronomodel.git
```

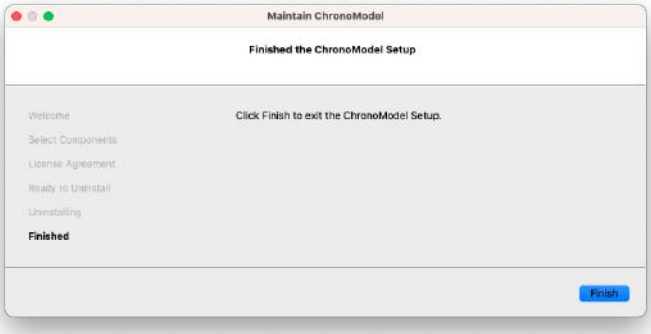
  and compile the application yourself.

3 Uninstall

In the directory containing the ChronoModel application, you will find an software "Chronomodel_uninstaller" that allows you to uninstall the application. Double-click the software. Following the wizard window, the software is uninstalled and the directory is deleted. You may need administrator rights.




Maintain ChronoModel
Ready to Uninstall
Welcome
Select Components
License Agreement
Ready to Uninstall
Uninstalling
Finished
All required information is now available to begin removing ChronoModel from your computer.
The program directory /Applications/Chronomodel 3.2.7 will be deleted completely, including all content in that directory!
< Back
Uninstall


Maintain ChronoModel
Finished the ChronoModel Setup
Welcome
Select Components
License Agreement
Ready to Uninstall
Uninstalling
Finished
Click Finish to exit the ChronoModel Setup.
Finish

4 Opening ChronoModel

4.1 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.

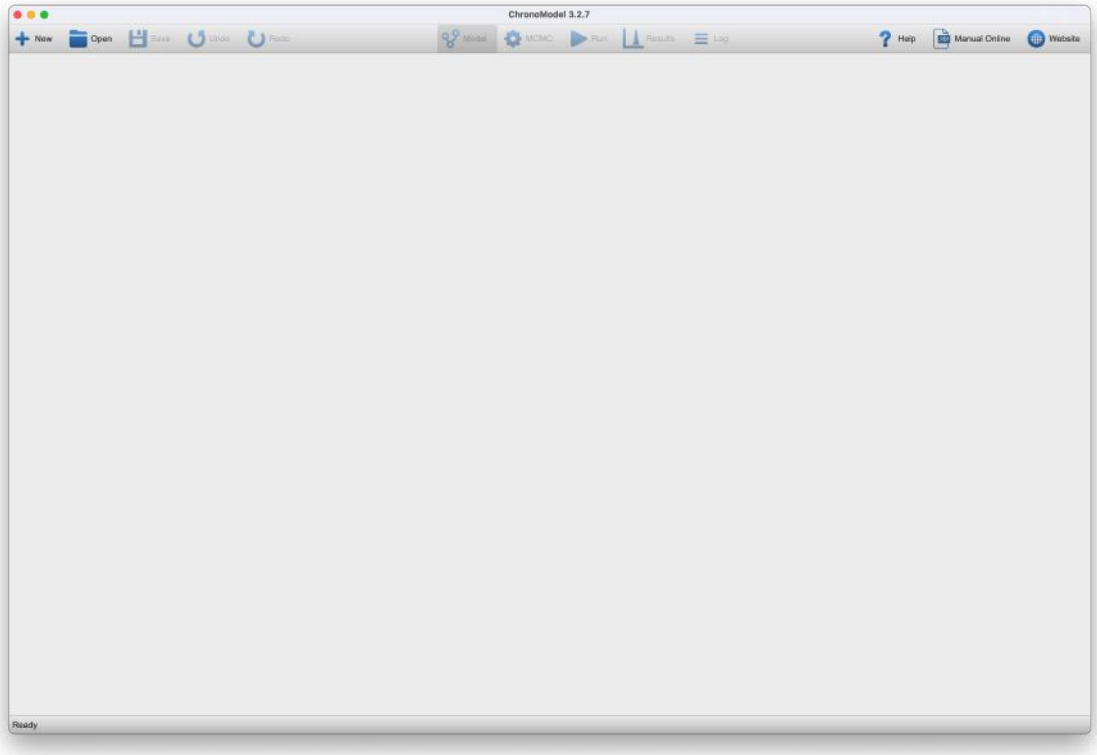


Figure 1: ChronoModel interface

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

4.1.1 Main menu

Depending on your system the main menu can appear differently.

Figure 2: on MacOS

Figure 3: on Windows

On MacOs, there is a chronomodel menu. Here you'll find the about and about Qt menus. The About menu recalls licenses and lists contributions. The About Qt menu reminds you that the project uses Qt and lists licenses. On window, these menus are accessible at the end of the menu bar after the Action menu.

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.

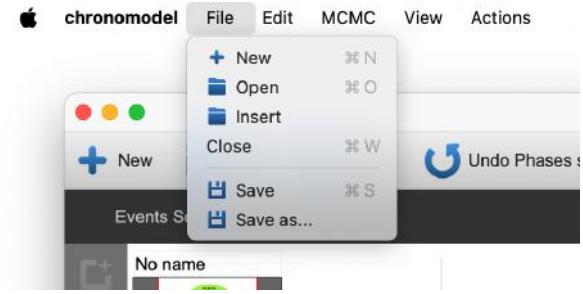


Figure 4: Top Menu File

With the Edit menu, you can Undo or Redo the last action on the scene.

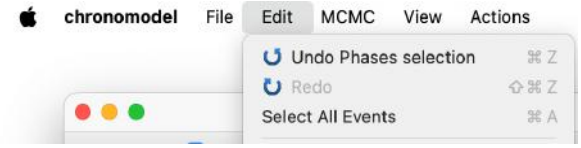


Figure 5: Top Menu Edit

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.

With the Actions menu, you have miscellaneous tools.

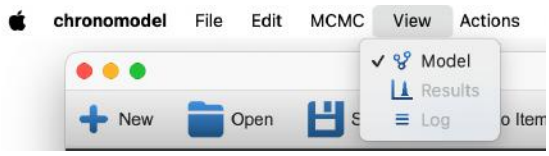


Figure 7: Top Menu View

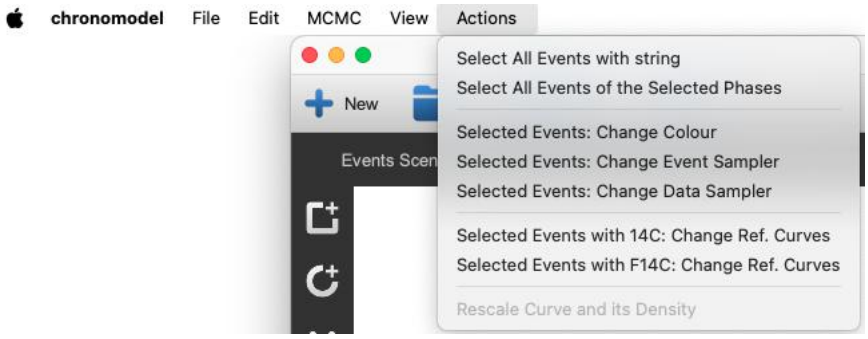


Figure 8: Top Menu Actions

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 Event Sampler A dialog box appears and you have to select the method you want to apply to the selected Events.

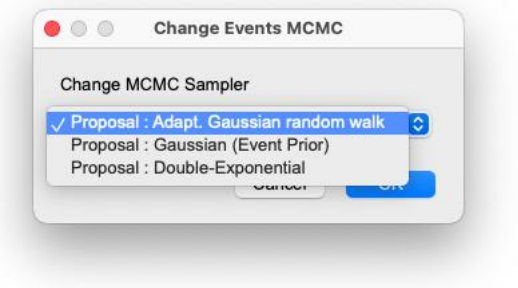


Figure 9: Change Events MCMC

Selected Events: Change Data Sampler 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.

A third part of the menu shows a tool for grouped actions only on 14C or F14C in selected Events to change the reference curve in all Data. Selected Events with 14C: Change Ref. Curves Selected Events with F14C: Change Ref. Curves These actions change all calibration curves for selected events using either the 14C plugin

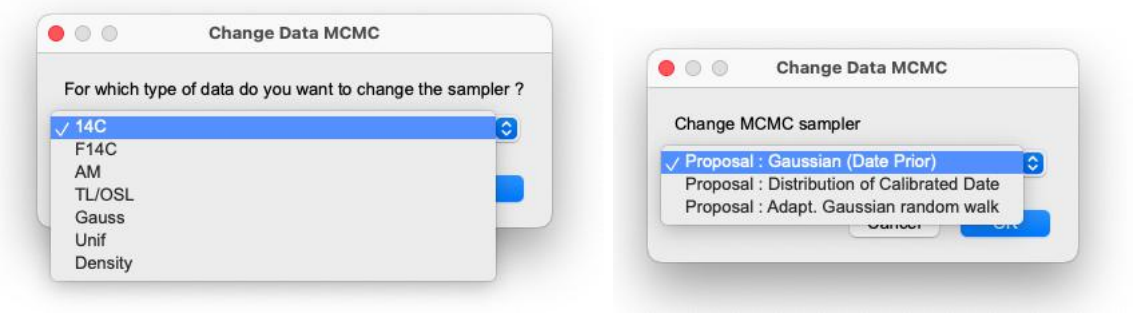


Figure 10: Change Events method

or the F14C plugin. Useful for updating a model.

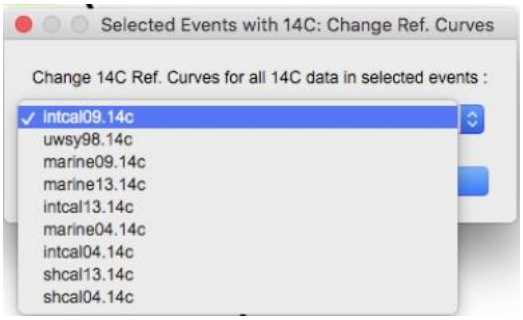


Figure 11: Top Menu change reference curve for 14C

Rescale Curve and its Density A fourth part of the menu presents a tool for grouped actions in curve mode only. This tool allows you to redraw curves and, if required, densities, by selecting them:

- For curve(s) and densities, the number of points on the time scale Time Step . The min and max on the time scale being the study period.

- For densities, you can define the min and max scale, as well as the number of definition points Value Step .

4.2 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.

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.

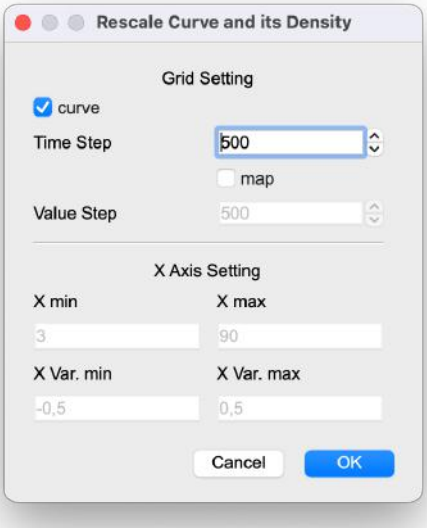


Figure 12: Menu Rescale Curve

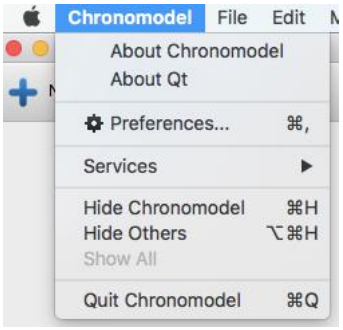


Figure 13: in MacOS

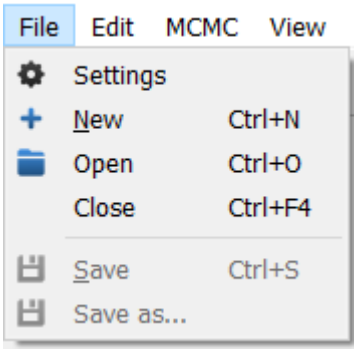


Figure 14: in Windows

4.2.1 Apply

This button closes the window, applying the changes made in the boxes. By default, it has the focus, which means that if you hit the carriage return key, the window

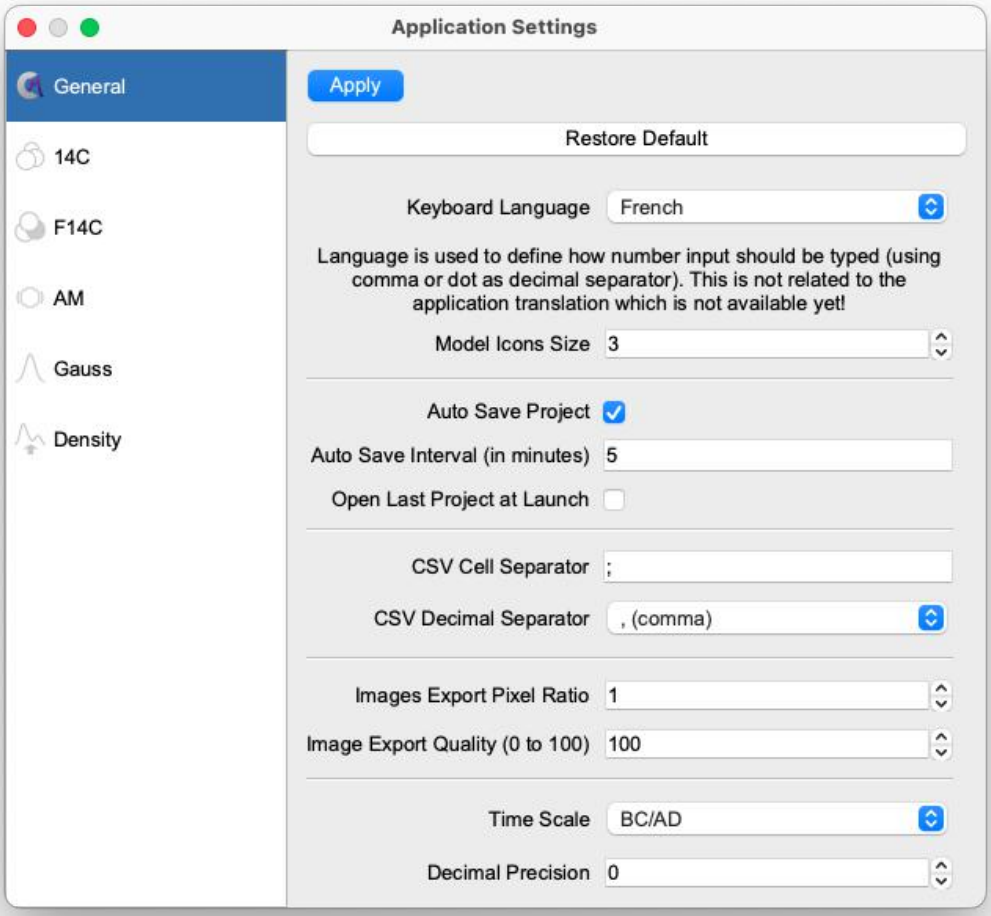


Figure 15: Application Settings

closes with the changes applied. If you don't want to apply the changes, you can close the window using the red control buttons at the top of the window, managed by your operating system.

4.2.2 Restore Default

This button resets all parameter values to their default values.

- Keyboard Language; **is defined by your system**
- Model Icons Size ; **3**
- Auto Save Project; **unchecked**
- Auto Save Interval (in minutes) : **5**

- Open Last Project at Launch : **unchecked**
- CSV Cell Separator ; **semicolon**
- CSV Decimal Separator ; **comma**
- Images Export Pixel Ratio; **1**
- Image Export Quality (0 to 100); **100**
- Times Scale; **BC/AD**
- Decimal Precision; **0**

4.2.3 Keyboard Language

The Keyboard 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!

4.2.4 Model icons size

This spin box allows you to change the size of the tool icons on either side of the Events and Phases scenes, useful for small screens.

4.2.5 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.

4.2.6 Open Last Project at Launch

This checkbox allows you to open the last project saved when opening ChronoModel.

4.2.7 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.*

4.2.8 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.

4.2.9 Time Scale

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
- Age cal. B2K: Ages calibrated Before 2000. Corresponds to *2000* - t
- Date cal. BP: Dates calibrated Before Present. Corresponds to t - *1950*
- Date cal. B2K: Dates calibrated Before 2000. Corresponds to t - *2000*
- BCE/CE: same as BC/AD

4.2.10 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.

4.2.11 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.

4.3 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.

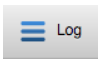
In the middle of the window, the icons refer to different steps of the modeling with ChronoModel.

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:

Activates or deactivates the context-sensitive tips seen in yellow bubbles. By defaults, Help is active.

Reaches the user manual on the web site.

Link to the ChronoModel website.

4.4 Create a project

In order to create a new project, click on

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 16).

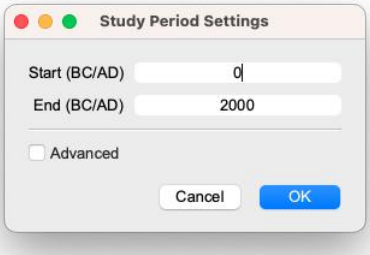


Figure 16: Dialog box to define the study period

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 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 17, 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.

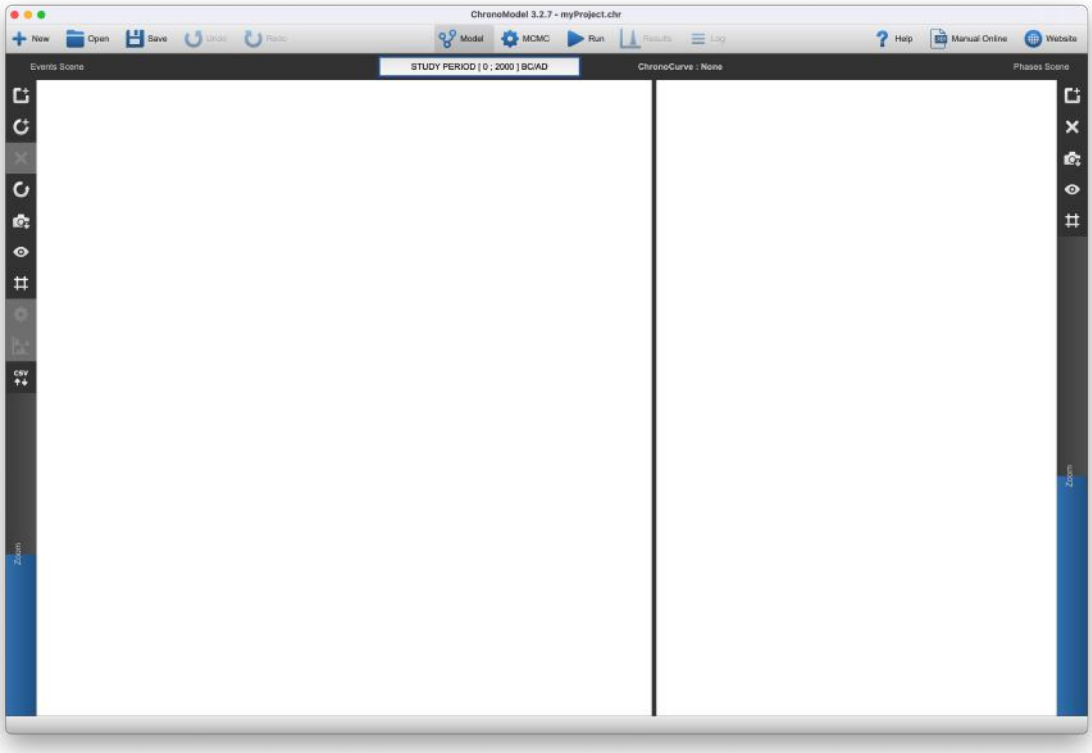


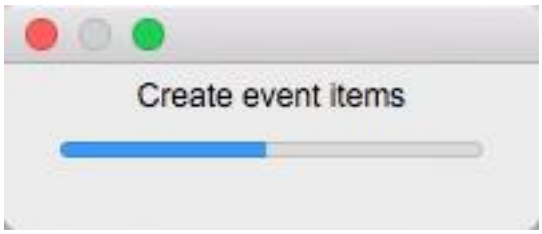
Figure 17: The interface of ChronoModel when starting a new project. On the left-hand side of the window, the Events scene, on the right-hand side, the Phases scene.

4.5 Opening an existing project

To open a pre-existing project, use the

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".

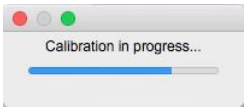
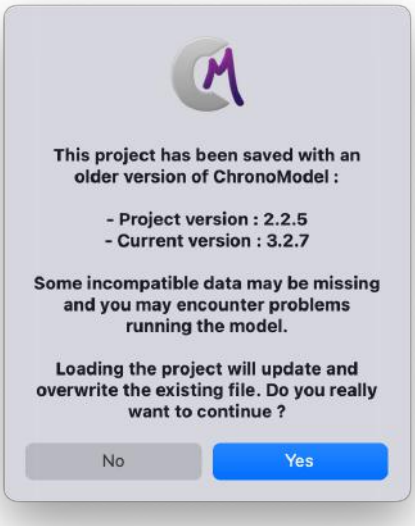
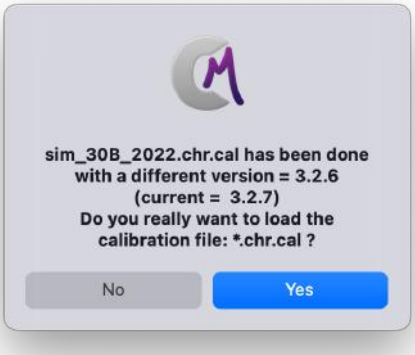


Figure 18: Calibration computation on the full model

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" and "chr.res"). If in doubt, this auxiliary file "chr.cal" can be ignored. The *.res files are not guaranteed to be compatible between versions. You can delete them yourself using your file manager.



4.6 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 16). *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 . Without any change on your part with this option, calibration densities have a step adapted to the step of their calibration curve and to the value of the measurement. This means that each datation has its own resolution step.

In some cases, often when doing theoretical tests, you can change this setting.

In this case, you check the box and can modify the value in the field Resolution in years . You will then see a warning box to validate. 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. The default value is 1 year.

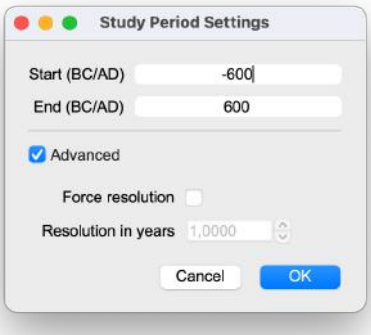


Figure 19: Advanced option in the study period setting

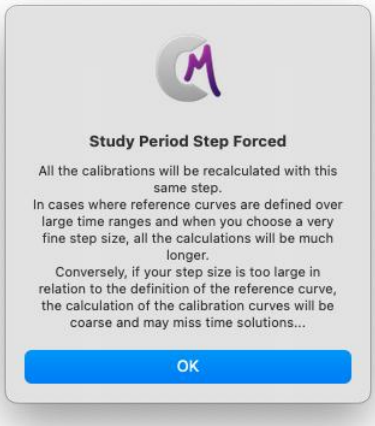


Figure 20: Warning Study Period Step Forced

5 Model: Events scene

5.1 Creating an Event

To create a new Event, select on the left-hand side of the Events scene (see Figure 17). 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.

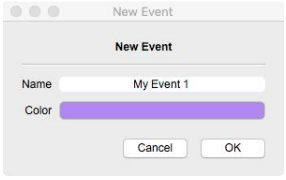


Figure 21: Basic dialog box for the Event

Figure 22: Dialog box to change the color of the Event item

After validation, the Event appears in the Events scene (See Figure 23).

5.2 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 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. Double-Exponential (this is the default setting)
2. Event Prior
3. adapt. Gaussian random walk

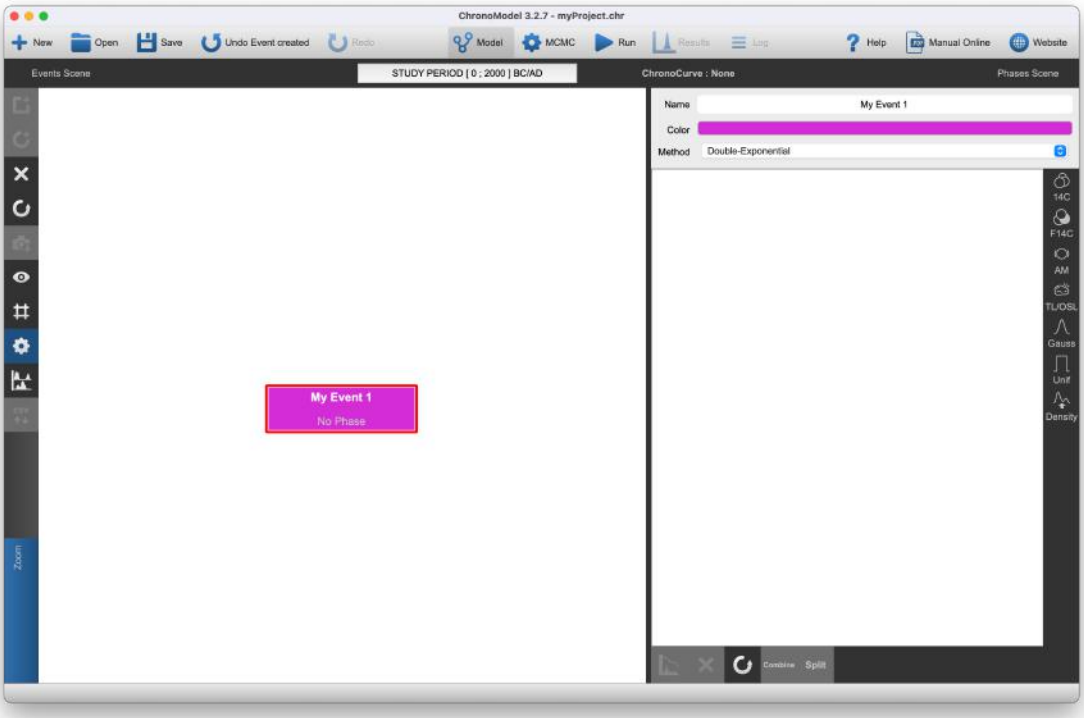


Figure 23: Chronomodel window showing the new Event in the Events scene

5.3 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

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.

Since version 2.0, we've added 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

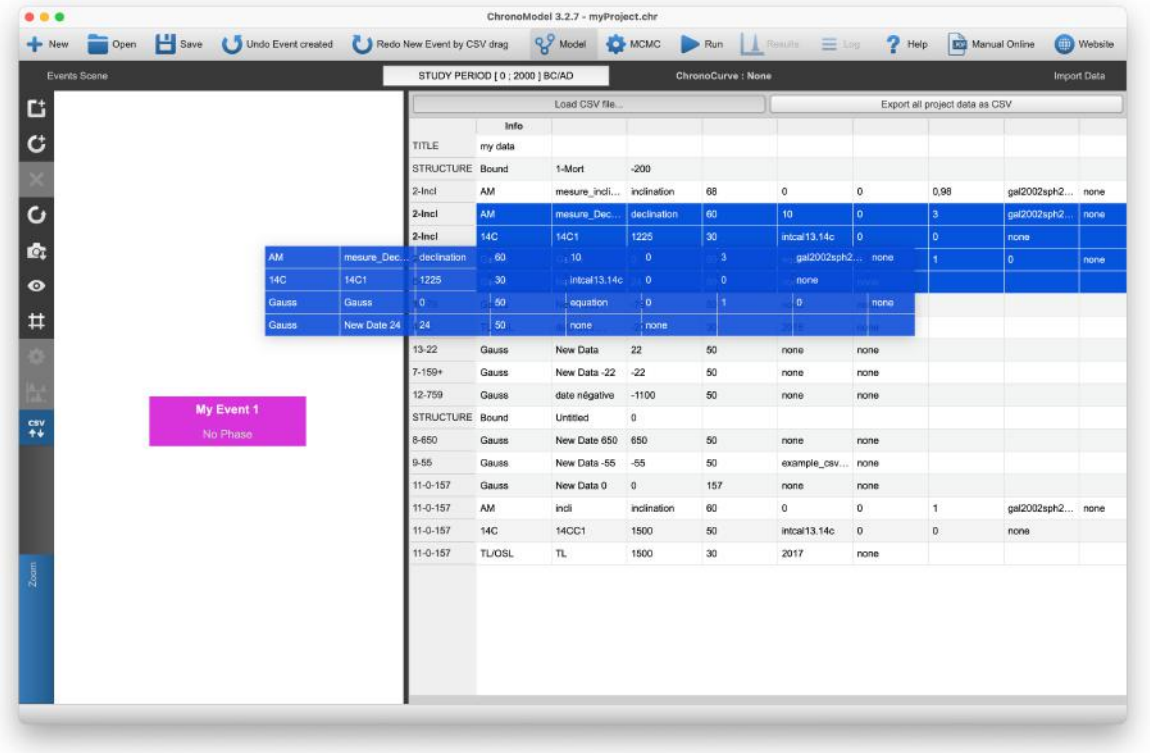


Figure 24: Inclusion of information dragged from a CSV file

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. If you drag more than 4 dates onto the Events scene, a window 25 will allow you to directly create chronological links between these Events. You can link Events with the youngest at the top of the list, the oldest at the top, or not link at all.

Be aware that by default ChronoModel reads a CSV file using a comma as a cell separator and a dot as a decimal separator. In the Application Settings presented in Figure 26, these options can be changed.

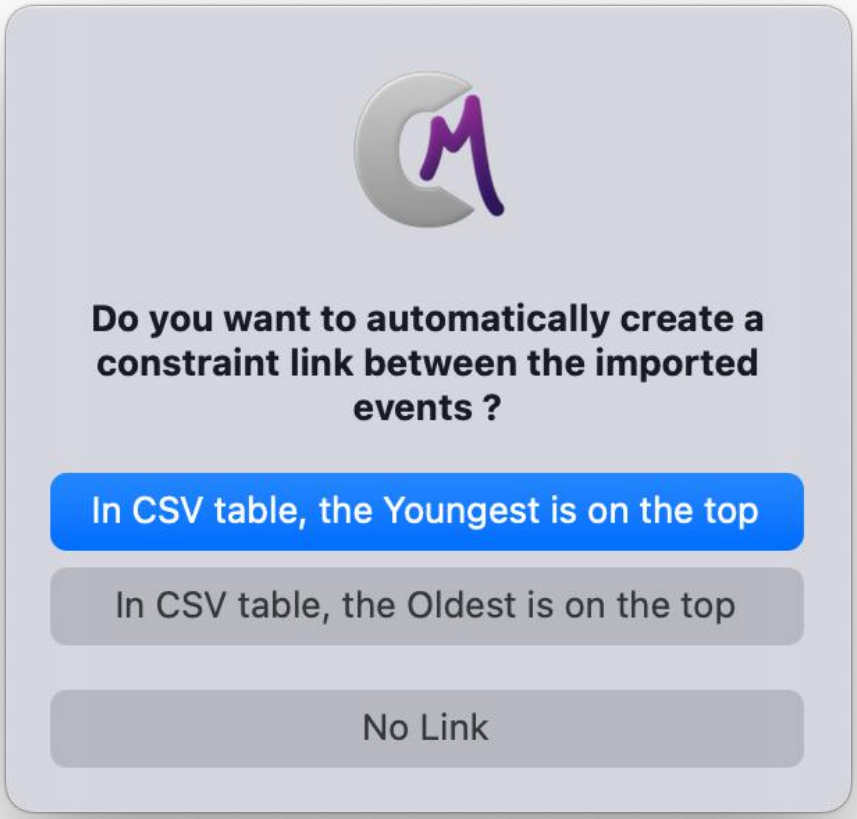


Figure 25: Automatic link

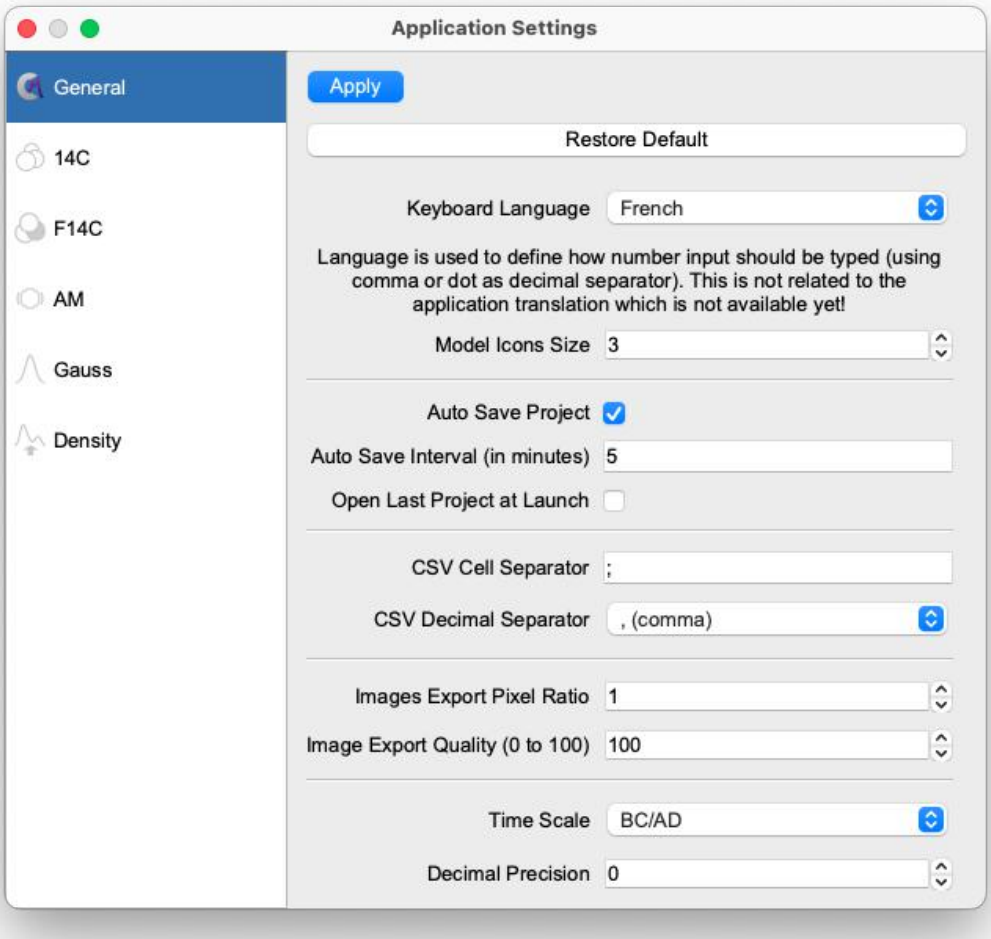


Figure 26: Application settings

5.3.1 Radiocarbon date (14C)

Clicking on

, the radiocarbon extension window will be opened (See Figure 27). 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://calib.org/marine/).

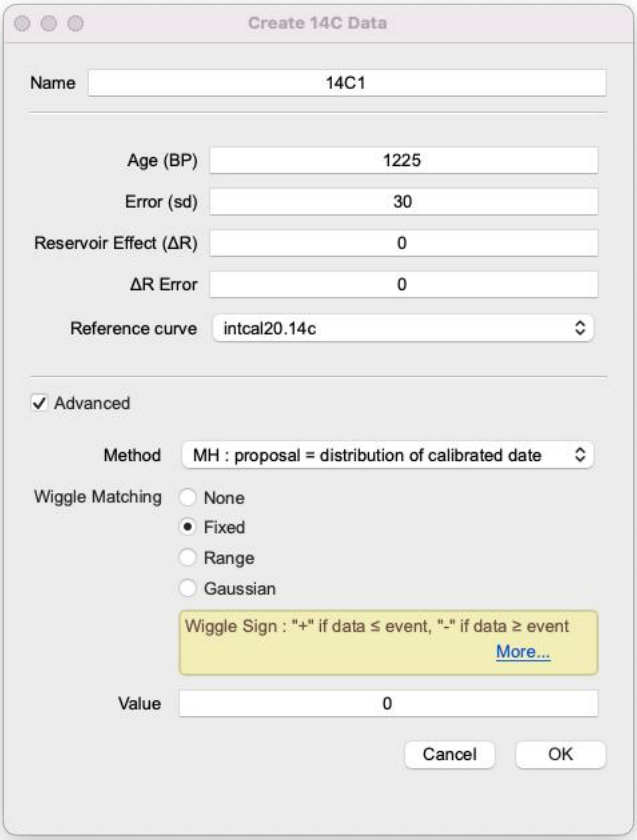


Figure 27: The radiocarbon measurement extension window with advanced options

When adding a radiocarbon date, you can select one of these reference curves using the drop-down menu. The ChronoModel application installer no longer systematically installs calibration curves. This is to avoid deleting any personal curves.

These curves are listed in Table 1.

Other curves may be included in ChronoModel from the Application Settings . Figure 28 shows the window from which it is possible to add a new reference curve, or the curve installer supplied separately.

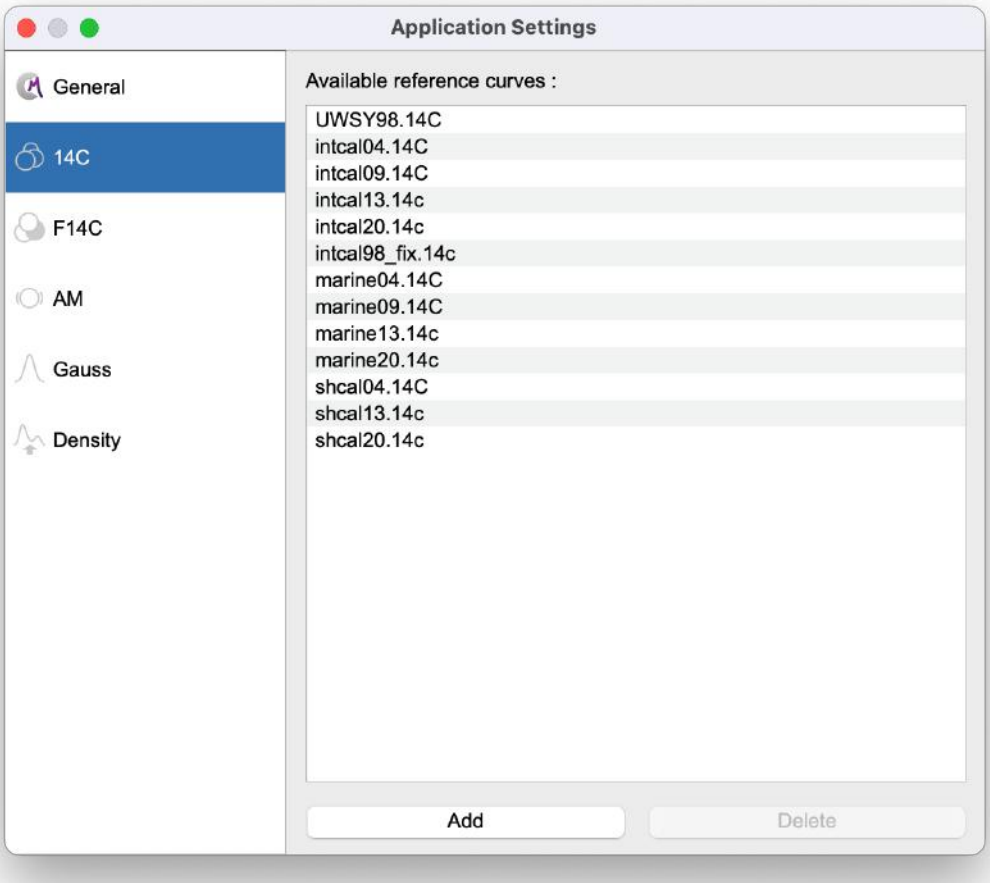


Figure 28: Application Settings - Reference curves for 14C date

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)
IntCal20	Reimer et al. (2020)
Marine20	Heaton et al. (2020)
ShCal20	Hogg et al. (2020)

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

5.3.1.1 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 27).

The default MCMC method used for radiocarbon dating 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.

Once the measurement is validated, its details appear in the Properties tab as shown in Figure 29 and can be changed by double-clicking on its name from the list of measurements.

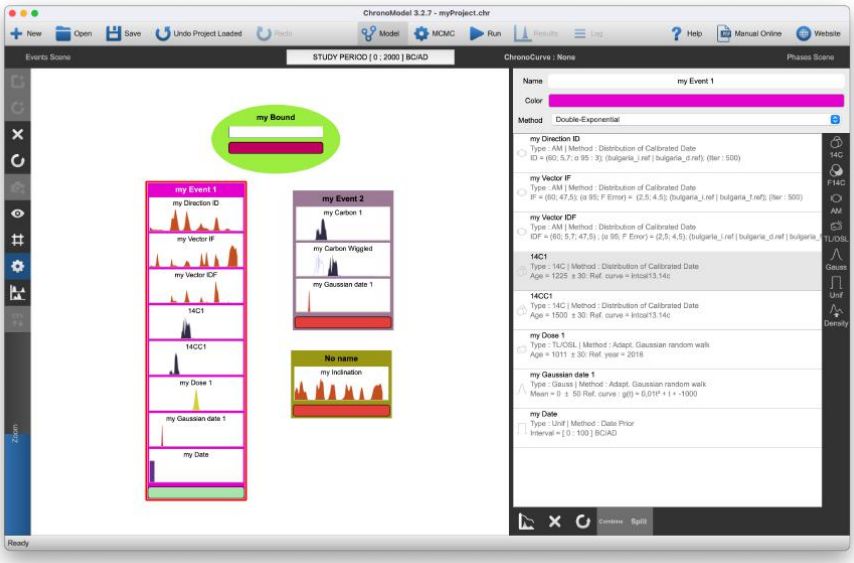
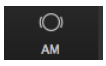


Figure 29: Events scene and Properties

5.3.2 Archaeomagnetic date (AM)

Click on 

to open the extension window associated with archaeomagnetic dating, as displayed in Figure 30. In this window, you can insert the reference name of the measurement, choose the magnetic parameter (inclination, declination or field intensity) or directly select a Bayesian combination of 2 or 3 of these parameters. You can also choose the reference curve for the calibration process.

- If you choose Inclination (I) : enter its value and its alpha 95 value. The

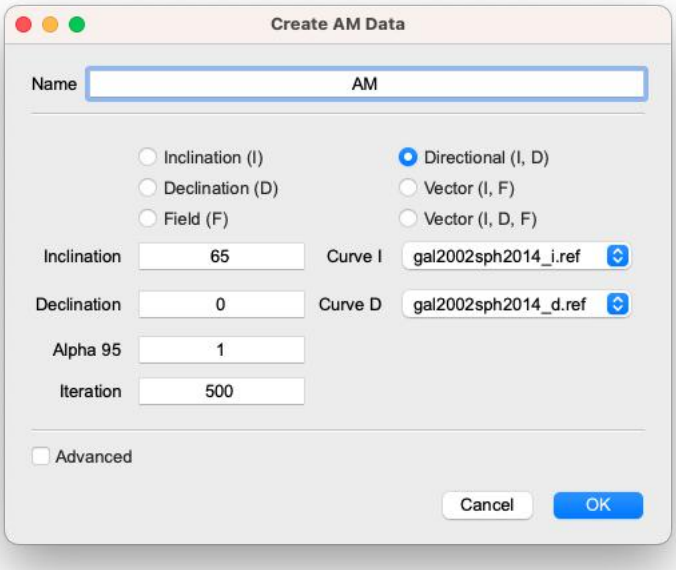


Figure 30: The archaeomagnetism extension window with advanced options

associated error is then calculated by

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

- If you choose Declination (D) : enter its value, the value of the Inclination associated 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 Field (F) : enter its value and its Error F .

- If you choose Directional (I, D) : Enter values for Inclination , Declination , associated alpha 95 and number of Iteration to be performed by integration

- If you choose Vector (I, F) : Enter values for Inclination , Field , associated alpha 95 , Error F and number of Iteration to be performed by integration

- If you choose Vector (I, D, F) : Enter values for Inclination , Declination , Field , associated alpha 95 , Error F and number of Iterations to be performed by integration

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 31 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)
Gwh2013uni_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

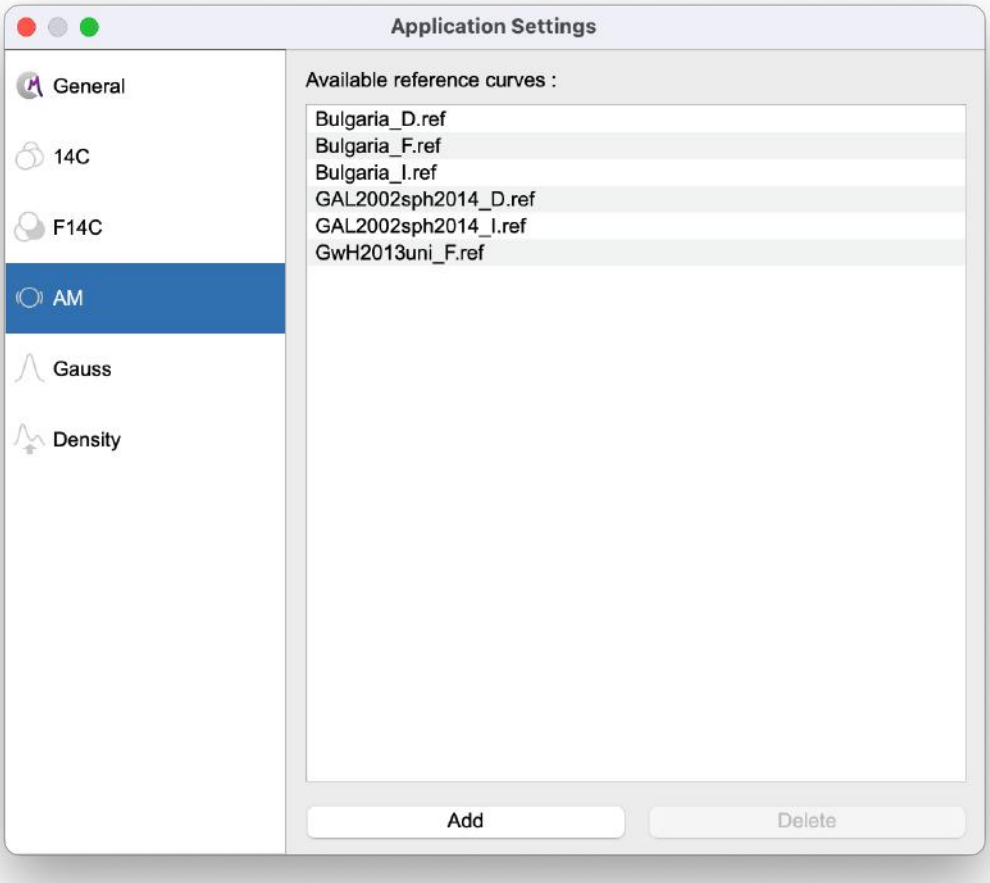


Figure 31: Application Settings - Reference curves for AM date

5.3.3 Luminescence date (TL/OSL)

Click on

to open the TL/OSL extension window as shown in Figure 32. A TL/OSL measurement is defined by its name, its Age , its Error (sd) and the year of reference Ref. year (BC/AD) . If you add reference curves, remember that the end of the curve name indicates which field parameter is calibrated. In other words, files ending in :

- "_ F.ref" correspond to field intensity calibration curves.
- "_ I.ref" correspond to inclination calibration curves.
- "_ D.ref" correspond to declination calibration curves.

The function of calibration associated is then

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

, where t_0 is the reference year in BC/AD.

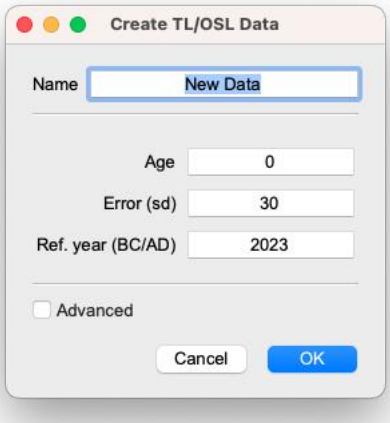


Figure 32: The TL/OSL extension window

5.3.4 Gaussian dating (Gauss)

Click on

to open the Gauss extension window as presented in Figure 33. A Gaussian date is defined by its name, its mean Measurement and its error Error (sd) . Measurement and Error are defined in *date format BC/AD*.

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)35. This is the default choice corresponding to the option None .
You can also customize your own calibration curve using the option 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, Figure 34. To do this, select the last option Use custom curve file and choose a file from the drop-down menu. If your file is not already included in ChronoModel, use the Application Settings window to add/delete another file. See Figure 15 that shows the window allowing to add a new reference curve.

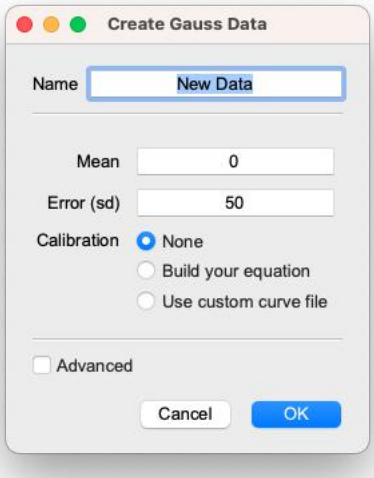


Figure 33: The Gauss extension window

Example of a file "exemple_csv_ref.csv" a toy reference curve between tmin =-2000 and tmax= 2000: This is a csv format with the UK standard (separator: comma; decimal point) with 3 columns. The step may not be regular.

- the date in BC/AD
- average value

Figure 34: The Gauss extension window with file reference

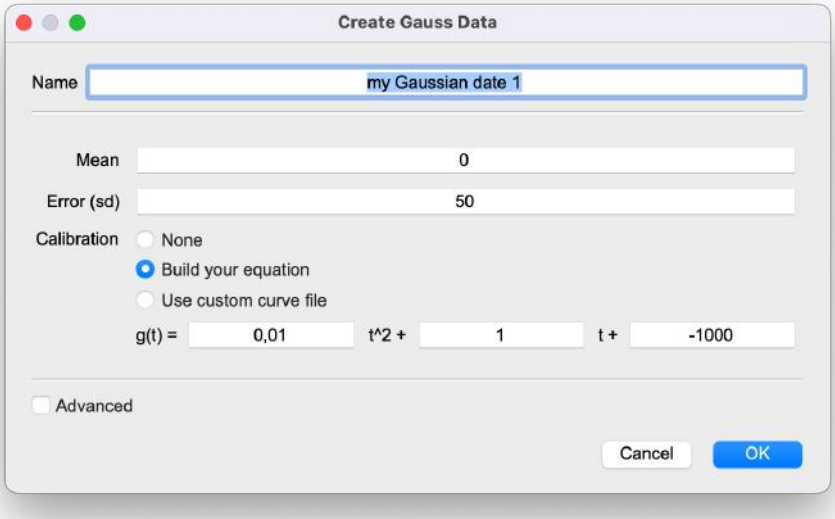


Figure 35: The Gauss extension window with equation

- the error (standard deviation), assumed to be Gaussian

```
-2000,10,5
-1000,1500,10
-0,1500,10
500,-1500,8
2000,20,2
```

The curves may be included in ChronoModel from the Application Settings . Figure 36 shows the window from which it is possible to add a new reference curve.

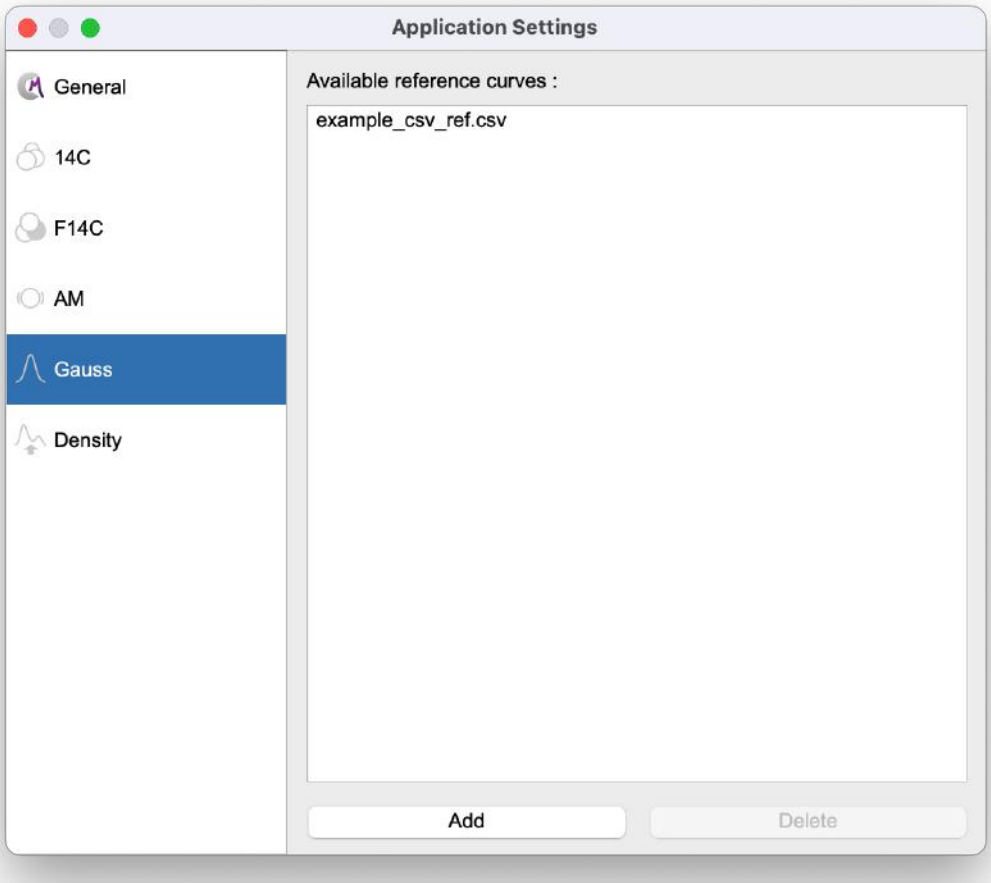


Figure 36: Application Settings - Reference curves for Gaussian date

5.3.5 F14C date (F14C)

Clicking on

, the radiocarbon extension window will be opened (See Figure 37). Within this window, you can insert the reference name of the measurement, the fraction value given by the laboratory (F14C), its associated standard error (Error (sd)).

In ChronoModel, several calibration curves are already implemented. These curves are listed in Table 3. When adding a fraction, 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 38 shows the window from which it is possible to add a new reference curve.

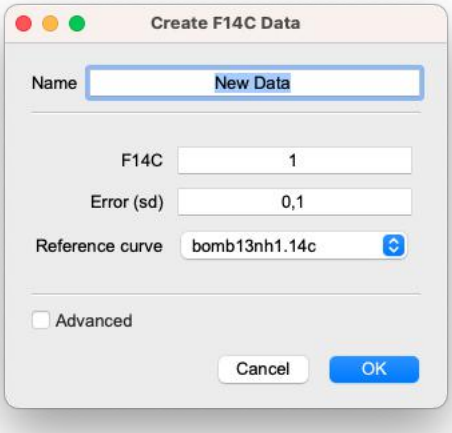


Figure 37: The F14C extension window

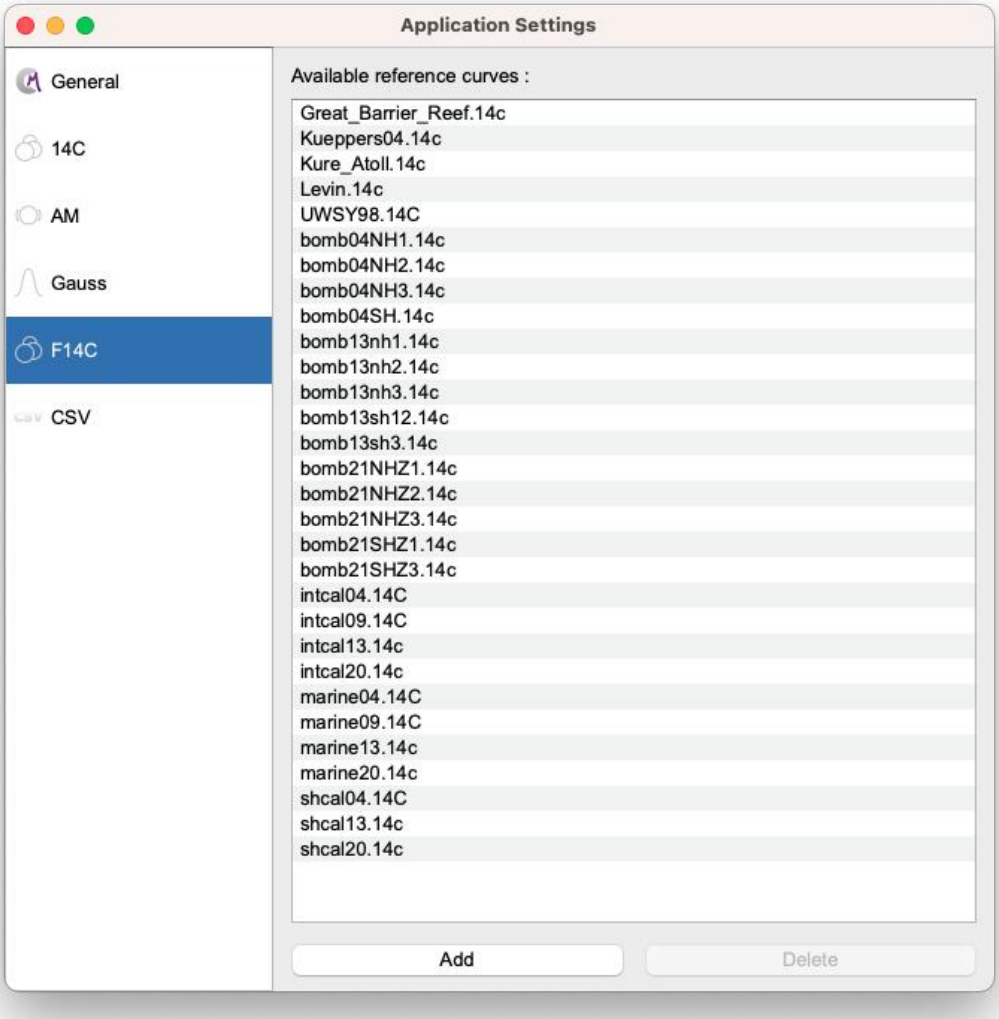


Figure 38: Application Settings - Reference curves for F14C date

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)
IntCal20	Reimer et al. (2020)
Marine20	Heaton et al. (2020)
ShCal20	Hogg et al. (2020)
Great_Barrier_Reef	Wu et al. (2021)
Kueppers04	Kueppers et al. (2004)
Kure_Atoll	Andrews et al. (2016)
Levin	Levin and Kromer (2004)
bomb04NH1	Hua et al. (2004)
bomb04NH2	Hua et al. (2004)
bomb04NH3	Hua et al. (2004)
bomb04SH	Hua et al. (2004)
bomb13nh1	Hua et al. (2013) Reimer et al. (2020)
bomb13nh2	Hua et al. (2013) Reimer et al. (2020)
bomb13nh3	Hua et al. (2013) Reimer et al. (2020)
bomb13sh12	Hua et al. (2013) Reimer et al. (2020)
bomb13sh3	Hua et al. (2013) Reimer et al. (2020)
bomb21NHZ1	Hua et al. (2021)
bomb21NHZ2	Hua et al. (2021)
bomb21NHZ3	Hua et al. (2021)
bomb21SHZ1	Hua et al. (2021)
bomb21SHZ3	Hua et al. (2021)

Table 3: Reference curves for F14C dating implemented in ChronoModel

5.3.6 Uniform density (Unif)

In version 1, this plugin was called typo-chronological reference (Typo). But it can be used for so much more. Click on

to open the Unif extension window (See Figure 39).

A uniform density is defined by its name, Lower date and Upper date , with the constraint that the Lower date must be the earliest. The difference may therefore be less than one year. But values can be decimal. Date is assumed to be defined in date format *BC/AD*

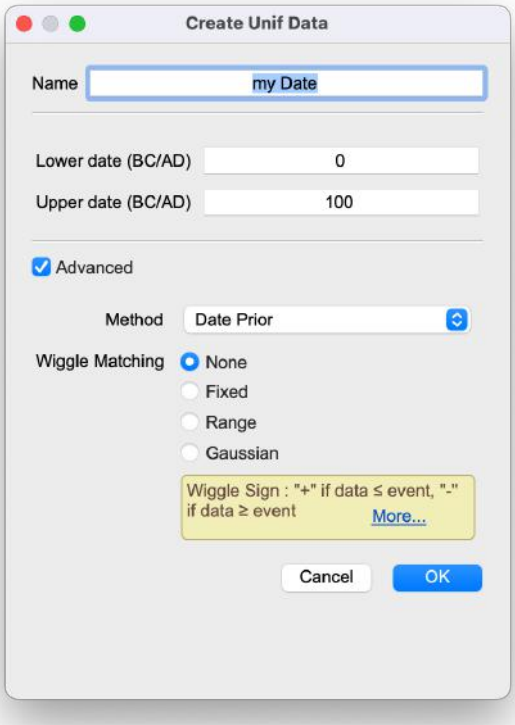


Figure 39: The uniform measurement extension window with advanced options

5.3.7 External density (Density)

This is the way to introduce a density curve calculated elsewhere, with another software program. click on

to open a dialog box allowing you to choose a file corresponding to the density you wish to import(See Figure 40). The **UK CSV file format** is as follows, it's mean decimal separator is dot and value separator is coma:

The first two lines are the min and max dates in BC/AD. The following lines show

the density values, including the extreme values. That is, if tmin = 0 and tmax = 100 with a step of 1 year, there must be 101 values.

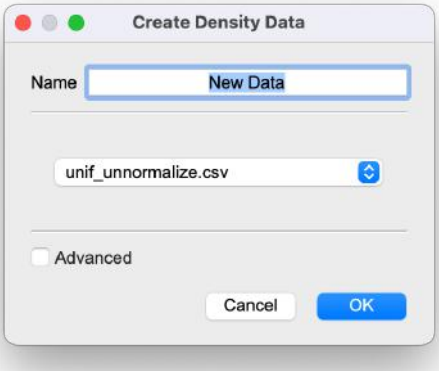


Figure 40: The CSV extension

The step size is deduced from the number of density data. The file can contain comments preceded by :

```
//
```

Example of a Gaussian distribution between tmin =-10 and tmax 10 (step = 1, so 21 values):

```
//norm( mean = 0, sd = 2)
-10
10
7.433598e-07
7.991871e-06
6.691511e-05
4.363413e-04
2.215924e-03
8.764150e-03
2.699548e-02
6.475880e-02
1.209854e-01
1.760327e-01
1.994711e-01
1.760327e-01
1.209854e-01
```

```
6.475880e-02
2.699548e-02
8.764150e-03
2.215924e-03
4.363413e-04
6.691511e-05
7.991871e-06
7.433598e-07
```

Example of a uniform distribution between 20 and 40 BC/AD:

```
// unif [20; 40]
20
40
0.05
0.05
```

The density may be included in ChronoModel from the Application Settings . Figure 41 shows the window from which it is possible to add a new density curve.

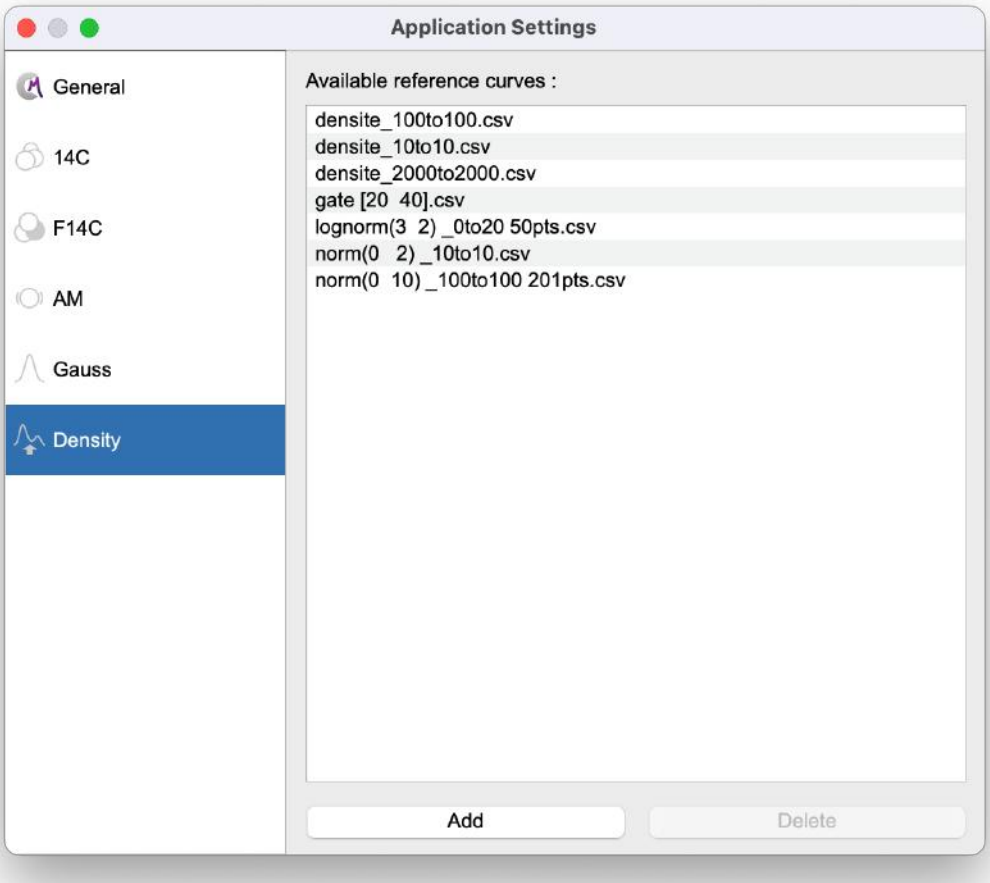


Figure 41: Application Settings - File for Date from external Density

5.4 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.

5.5 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.

5.6 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.

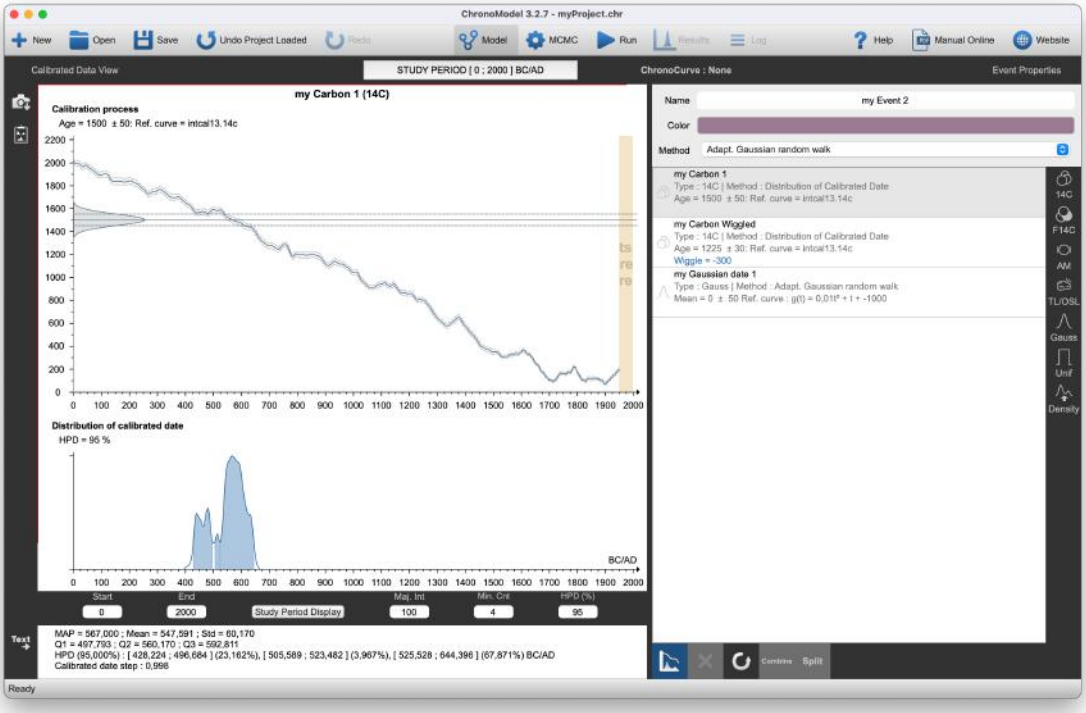


Figure 42: Calibration process of a radiocarbon date

At the bottom of the drawing, you'll find the descriptive statistics for the calibrated distribution.

On the bottom-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. A central button Study Period Display can reset the current period to the study period. You can change the HPD confidence level, all statistical results are then computed on the study period defined for the model and they are converted into the date format set in the Application Settings .

3 buttons on the left-hand edge allow you to save results. The button exports the graph to a file. The button to copy the graph to the clipboard. And The

button to copy the numerical result to the clipboard.

Deselect to see the Events scene again.

5.7 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.

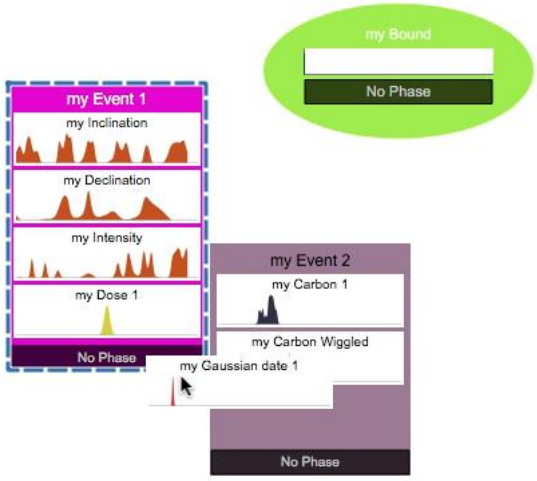


Figure 43: Moving Data to another Event

6 Data transfer

The 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.

6.1 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

6.1.0.1 Gaussian measurements

Example (in UK CSV format):

```
my Event 1,Gauss,myMeasurementName 1,24,50,none,none
my Event 2,Gauss,myMeasurementName 2,0,50,equation,0.01,1,-1000,none
my Event 3,Gauss,myMeasurementName 3,-55,50,example_csv_ref.csv,none
my Event 4,Gauss,myMeasurementName wiggled,0,50,equation,0.01,1,-1000,range,10,15
```

Description:
Cell 1: Event name
Cell 2: Gauss
Cell 3: Data 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"

6.1.0.2 Thermoluminescence measurements

Example (in UK CSV format):

```
my Event 1,TL/OSL,myDoseName,-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).

6.1.0.3 Radiocarbon measurements

Example (in UK CSV format):

```
my Event 1,14C,myCarbonName,1500,50,intcal13.14c,0,0,none
my Event 2,C14,myCarbonWiggledName,1225,30,intcal13.14c,0,0,range,10,15
```

Description:
Cell 1: Event name
Cell 2: 14C (or C14)
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).

6.1.0.4 Archaeomagnetic measurements

Example (in UK CSV format):

```
my Event 1,AM,myInclinationName,inclination,60,0,3,65,2,bulgaria_i.ref,,,none
my Event Dec 2,AM,myDeclinationName,declination,60,5.7,2.5,0,0,,bulgaria_d.ref,,none
my Event Field2,AM,myIntensityName,field,60,0,0,47.5,4.5,,,bulgaria_f.ref,none
my Event 1,AM,myDirectionIDName,incl-decl,60,5.7,3,65,2,500,bulgaria_i.ref,bulgaria_d.ref,bulgaria_f.ref,none
my Event 1,AM,myVectorIFName,incl-field,60,5.7,2.5,47.5,4.5,500,bulgaria_i.ref,bulgaria_d.ref,bulgaria_f.ref,none
my Event 1,AM,myVectorIDFName,incl-decl-field,60,5.7,2.5,47.5,4.5,500,bulgaria_i.ref,bulgaria_d.ref,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 "field" or "incl-decl" or "incl-field" or "incl-decl-field"

Cell 4: Inclination value

Cell 5: Declination value

Cell 7: α_{95}, the degree of α_{95} associated with the inclination and declination value

Cell 6: Field value

Cell 7: Error (sd) the standard error associated with the field value

Cell 8: Integration iteration, the number of iterations to execute to calculate the ID or IF or IDF combination

Cell 9: Reference curve for the inclination, the name of the file containing the reference curve associated with the measurement

Cell 10: Reference curve for the declination, the name of the file containing the reference curve associated with the measurement

Cell 11: Reference curve for the field, 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).

6.1.0.5 Unif Date

Example (in UK CSV format):

```
my Event 1,Unif,myDataName,-60,-50,none
```

Description:

Cell 1: Event name

Cell 2: Unif

Cell 3: Name, the name of the dated sample
Cell 4: Lower date
Cell 5: Upper date
The following cells are for the wiggle.

6.1.0.6 F14C measurements

Example (in UK CSV format):

```
my Event,F14C,myMeasurementName,1.41,0.051,bomb13nh1.14c,none
```

Description:
Cell 1: Event name
Cell 2: F14C
Cell 2: Name, the name of the dated sample
Cell 3: the fraction, 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

6.1.0.7 External Density

Example (in UK CSV format):

```
my Event,Density,myDataName,myDensity.csv,none
```

Description:
Cell 1: Event name
Cell 2: Density
Cell 3: Name, the name of the dated sample
Cell 4: density CSV filename

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

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

Figure 44 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

	Method	Data Name	Age	Error (sd)	Ref. curve	ΔR	ΔR Error	none | fixed | ran	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 44: 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 45: CSV file with AM method selected

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, 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.

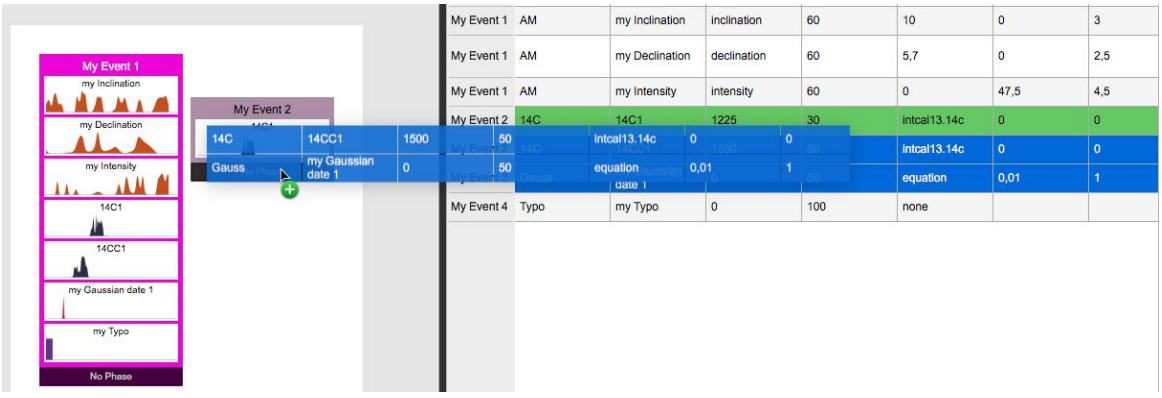


Figure 46: Insert by dragging Data into an Event

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.

6.1.1 Exporting Data

We can export the Data into a CSV file. On the top right in the CSV windows, there is a button

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 4.2.7

6.1.2 Hiding the Import Data panel

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

.

6.2 Creating a Bound

To create a new Bound in the Events scene, select 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 47). Now you need to switch on the property button 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. The date value must be in BC/AD format.

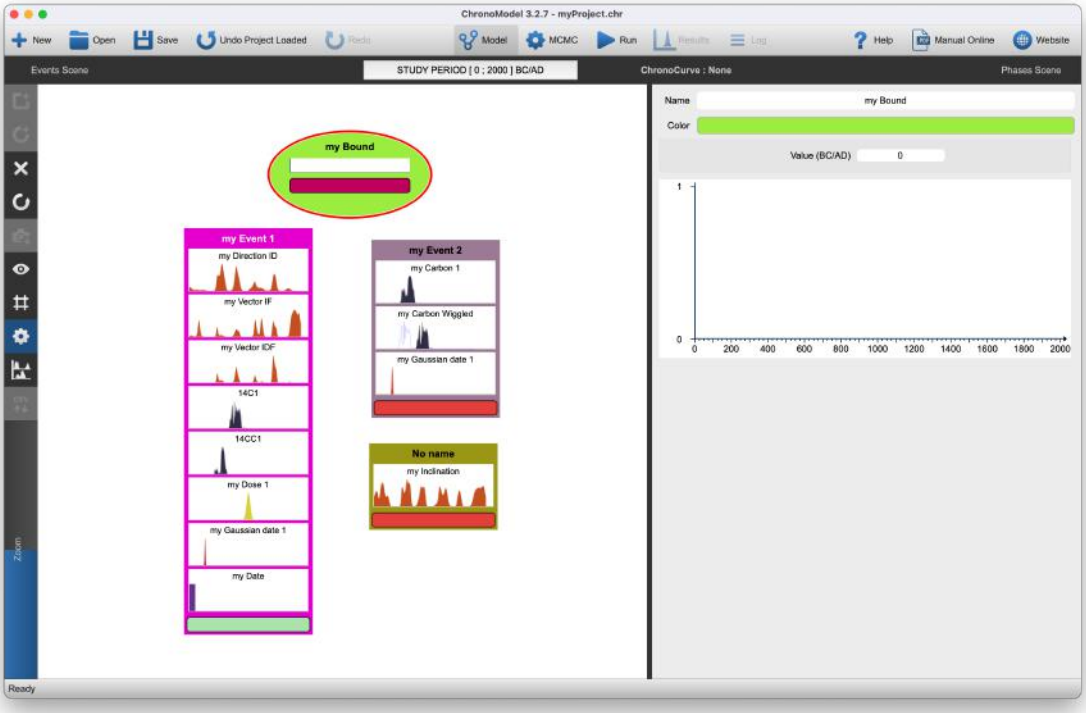


Figure 47: Creation of a new Bound in the Events scene

6.3 Modifying a Bound

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

6.4 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.

6.5 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 48: an Event containing measurements is restored with all its measurements, at the same place before deleting.

Figure 48: Window presenting all Events or Bounds that can be restored

6.6 Ordering constraints between the Events

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

6.6.1 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 49: Events scene showing a constraint between 2 Events

In the following example, there is a circular constraint.

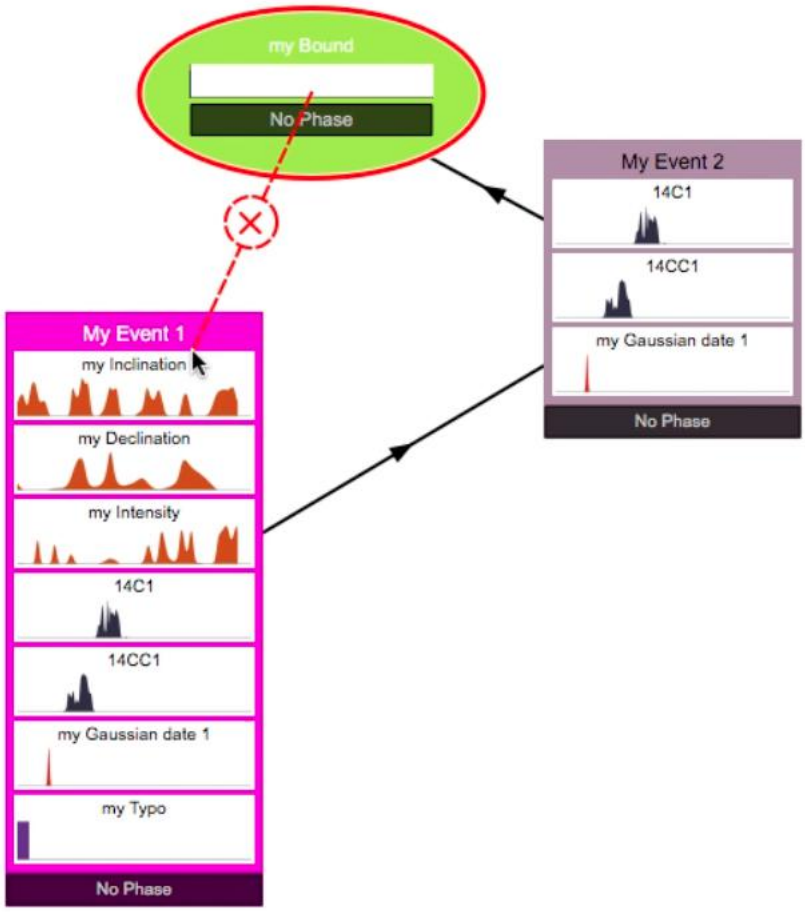


Figure 50: Events scene showing a bad constraint between a Bound and an Event

6.6.2 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.

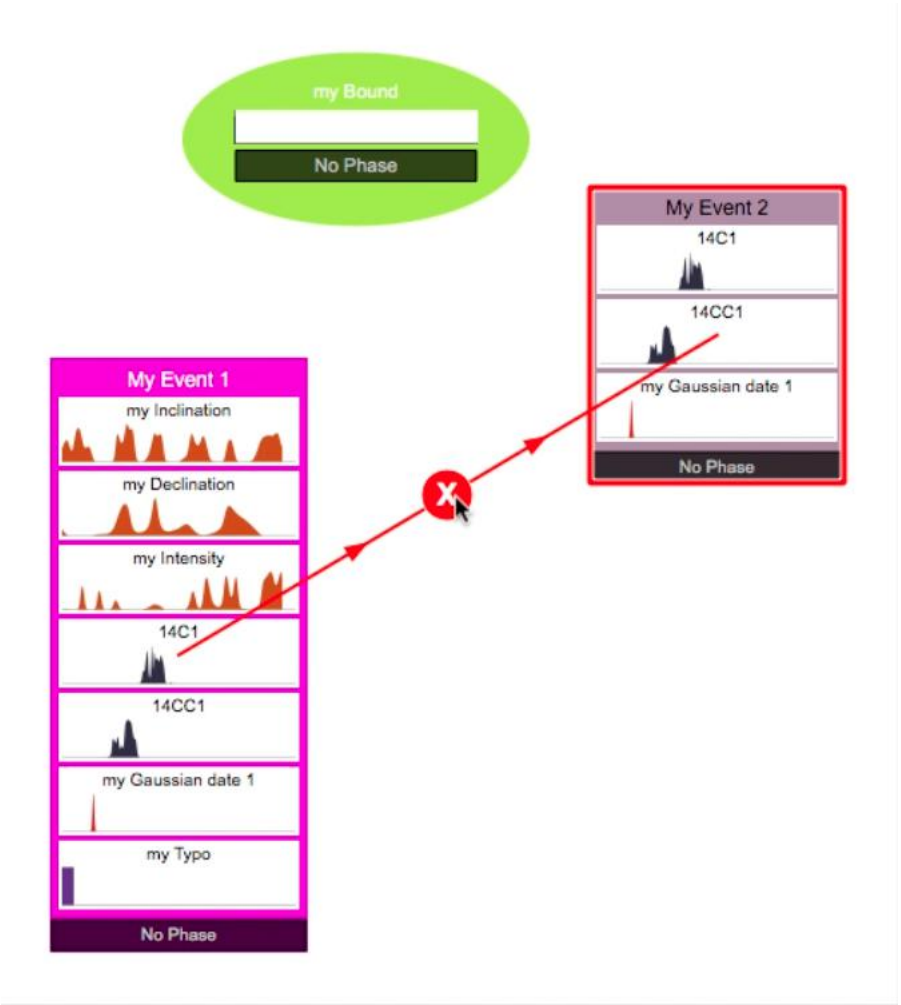


Figure 51: Events scene showing a constraint ready to be deleted

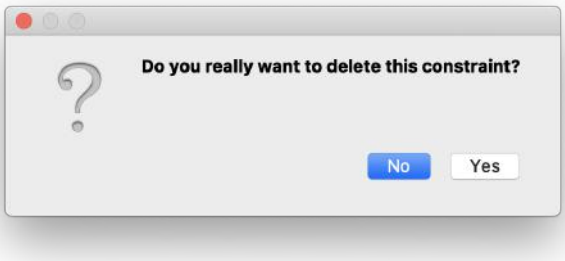


Figure 52: Confirmation box to delete a constraint

6.7 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.

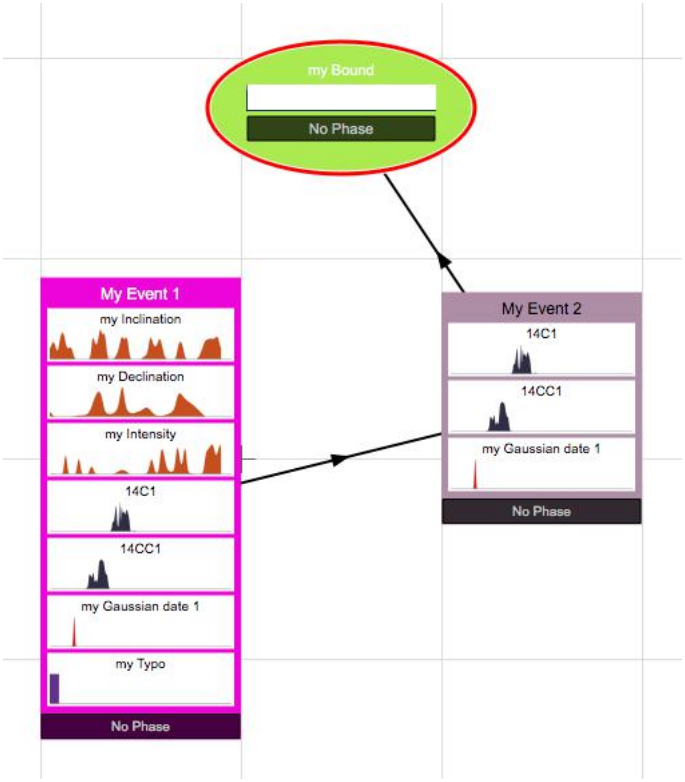


Figure 53: Events scene with magnetic grid

6.8 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.

6.9 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.

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.

6.10 Exporting the image of the Events scene

You may also export the image of the Events scene by clicking on the 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 15)

6.11 Advanced options

6.11.1 MCMC Method

You may want to change the MCMC method used to sample from the posterior distribution of the calibrated date associated with that date (See 10 section for more details on MCMC methods). The default MCMC method used for Gaussian 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.

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

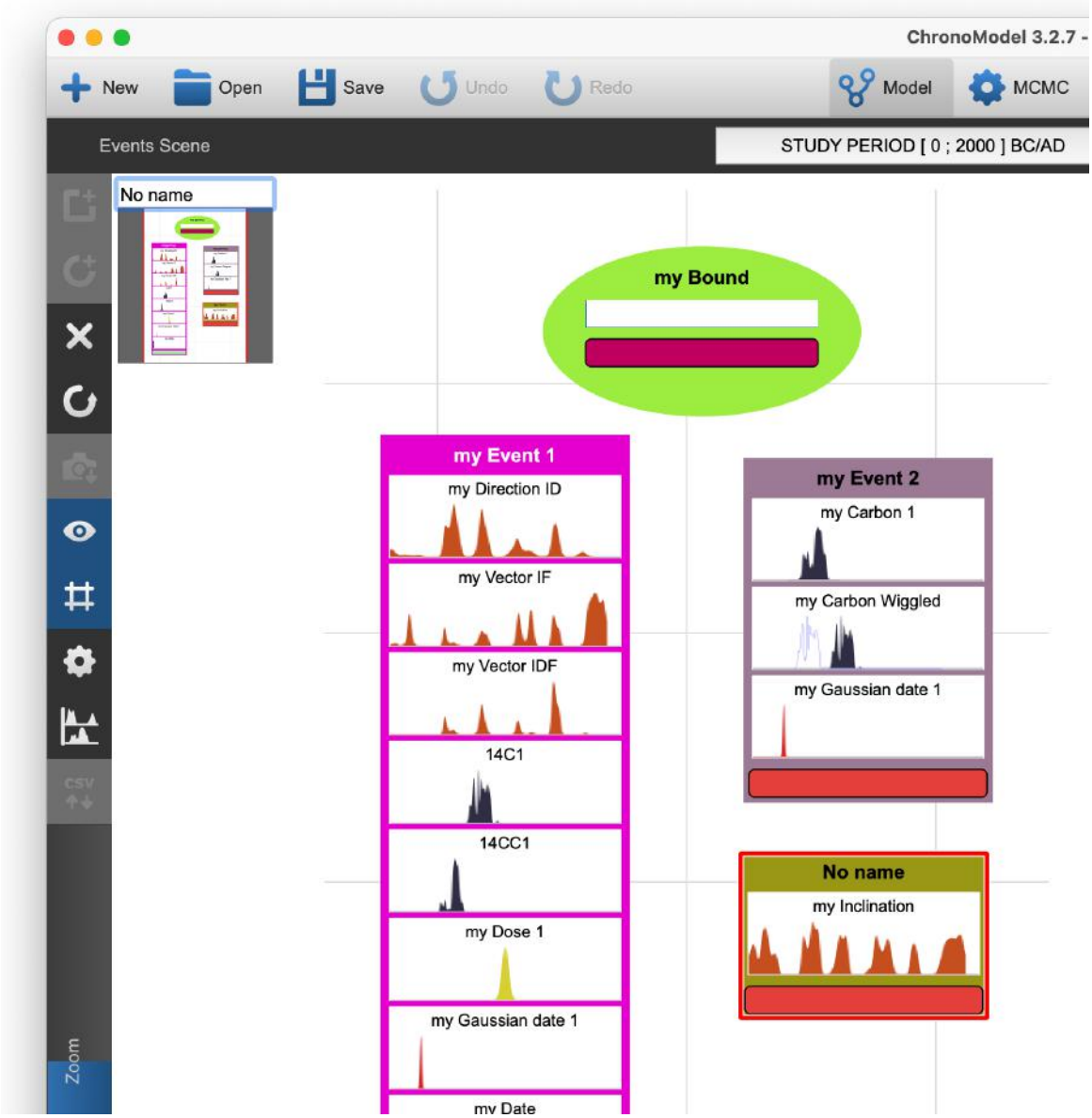


Figure 54: Events scene showing answer to the Overview search

(See Figure 55).

The default MCMC method used for radiocarbon dating 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.

Once the measurement is validated, its details appear in the Properties tab as shown in Figure 55 and can be changed by double-clicking on its name from the list of measurements.

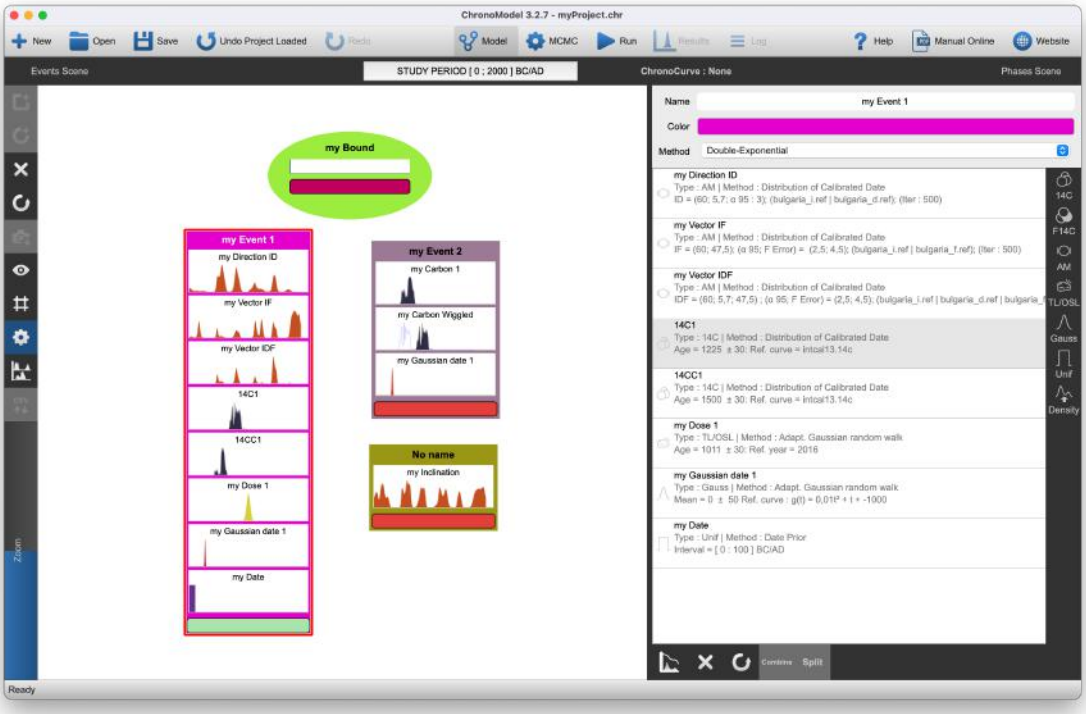


Figure 55: Events scene and Properties

6.11.2 Wiggle Matching

Most dates can be shifted using a wiggle matching process, except AM and TL/OSL dates. The wiggle matching may be none, 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 none.

6.12 Combining Date

Several dates from the same event, relating to the same sample, can be "combined" if they come from the same method (same plugin).

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 C. Click on Split to split back the measurements.

The combination may not be numerically feasible. A warning appears.

Remark : Dates must have the same reference curve, in the case of calibration dating.

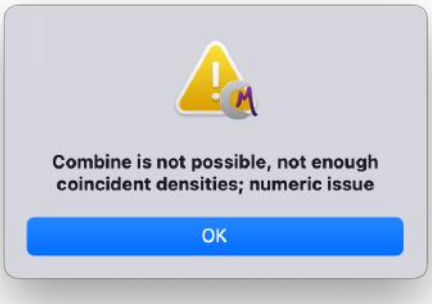


Figure 56: Impossible to combine

7 Model: Phases scene

In the main window in figure 17, 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.

7.1 Creating a Phase (eventually with 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 57.
This dialog box asks for the name and the color given to the Phase and its maximum duration which is set to Unknown by default.

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 58. 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 60.

Moreover, in this version 3 of ChronoModel, a third option has been added, called Uniform Span , figure 59. This option indicates that the span of event dates in the phase is assumed *a priori* to be uniform.

7.2 Modifying a Phase

To modify a Phase, double-click on it and the dialog box presented in Figure 57 will be reopened.

7.3 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

on the main menu.

7.4 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 61

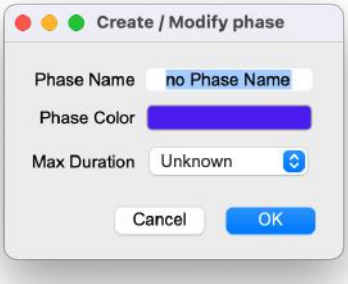


Figure 57: Basic dialog box for the Phase

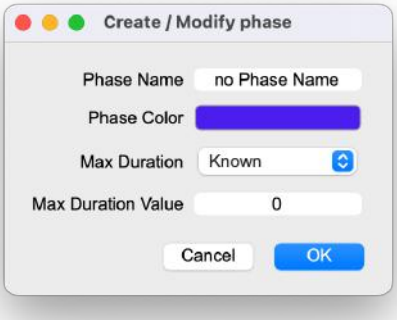


Figure 58: Dialog box to include prior information about the maximum duration of the Phase

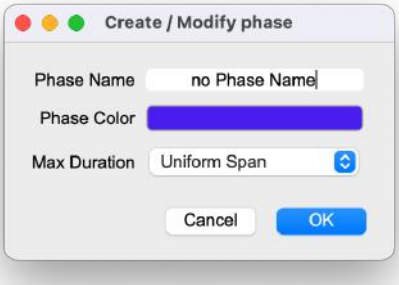


Figure 59: Dialog box to include prior information about the maximum duration of the Phase

Figure 60: Example of a Phase with prior duration

presents the inclusion of 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

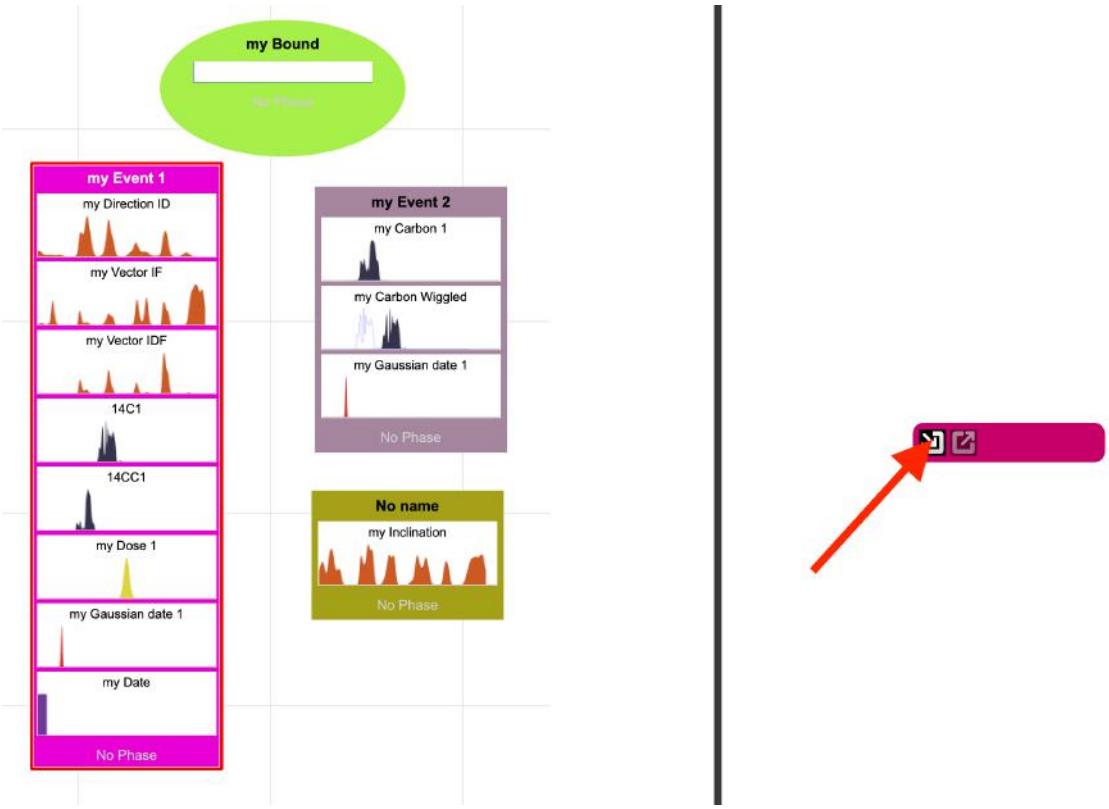


Figure 61: Including an Event in a Phase

Bound may also belong to several Phases. Now when you select an Event, it appears highlighted in one or several Phases it belongs to.

7.5 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.

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

7.6 Order constraints between the Phases

A succession constraint may relate two Phases.

Figure 62: Excluding Events from a Phase

7.6.1 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 63 displays an example. If the solution is not possible (Figure 64), just like in the Events scene, the arrow become a red dashed line with a cross.

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.

7.6.2 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

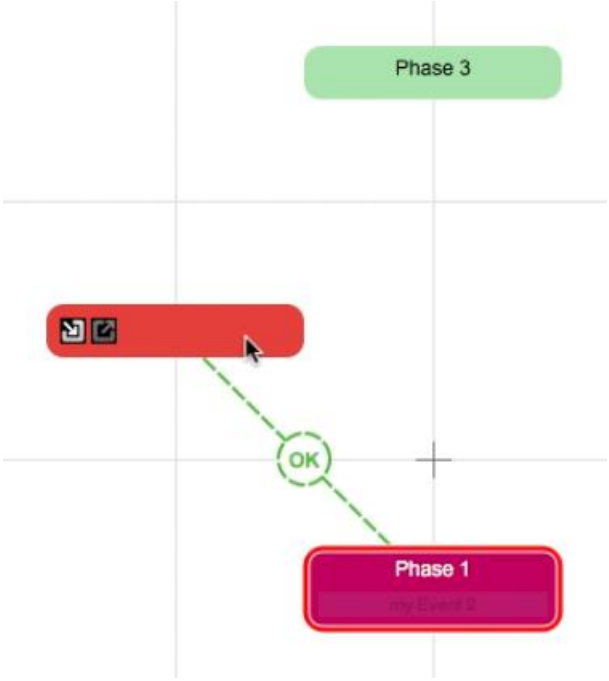


Figure 63: Possible constraint between two Phases

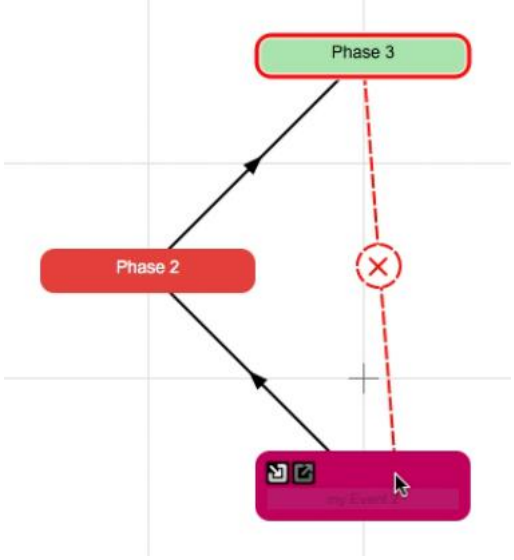


Figure 64: Impossible constraint between two Phases

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.

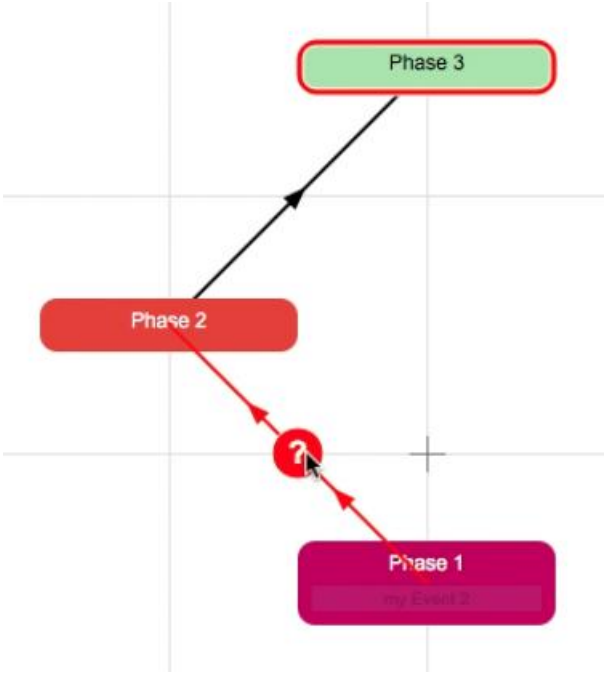


Figure 65: Constraint property access

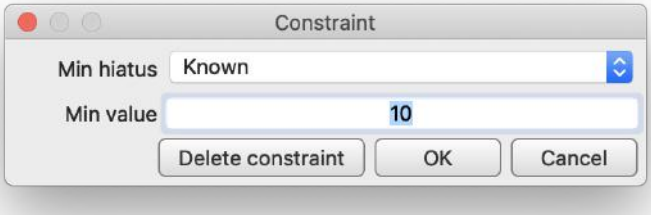


Figure 66: Setting minimal value for hiatus

7.6.3 Removing order constraints

To delete a constraint, go to the constraint property and in the dialog box click on Delete constraint .

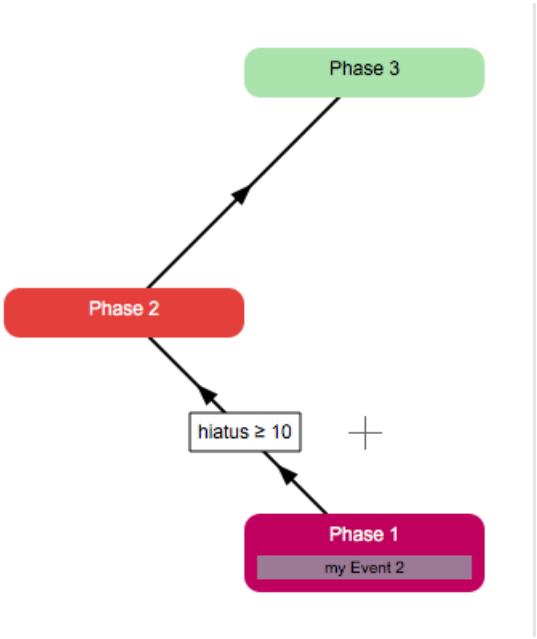


Figure 67: Order constraint with a hiatus indication

Figure 68: Dialog box to modify a hiatus between two Phases

7.7 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.

7.8 Phase overview

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

7.9 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.

8 Create a curve

Version 3 of ChronoModel allows you to assign one or more non-temporal dimensions to each Event. This dimension is used by ChronoModel to estimate a curve relating time to the parameter(s). This process corresponds to the generation of a reference (or calibration) curve. Only one functional model can be calculated, which may be multivariate. There may then be several estimated curves, but they will all use the same set of Events. This implies that all Events must have parameters. These curves can then be used to calibrate other Events not included in the model.

To activate curve processing, you need to activate functional link mode. This means that CM will look for a polynomial function (cubic spline) that relates dates to their values (measurements) for a curve..

To do this, click on the button to the right of the study period.

Figure 69: Click on this

When you select a curve calculation mode, an additional pink banner appears in each of the Events boxes. This banner reminds you of the data to be used to calculate the curve.

8.1 Curve process type

Use this window to select the curve calculation mode. There are 11 different modes.

- None : This is the standard mode in previous versions. There is no curve calculation. Just a chronological calculation.
- Univariate, dates are associated with a single variable; X
- Bi-variate, dates are associated with a point defined by two coordinates; X and Y
- Tri-variate, dates are associated with a point defined by three coordinates; X, Y and Z
- Depth, dates are associated with a single variable; Depth. In this mode, we use a continuous growth criterion. All curves are calculated, but only the increasing curves are retained. In some difficult cases, there may be no solution. The threshold criterion for the Minimal Rate of Change can be modified in the "Curve Parameters" windows

- Inclination, dates are associated with a single angular variable; inclination
- Declination, dates are associated with a single angular variable; Declination
- Field Intensity, dates are associated with a single variable Field
- Spherical (I, D), dates are associated with a point defined by two polar coordinates; inclination and declination.
- Unknown Dec (I, F), dates are associated with a point defined by one polar coordinates and one value; inclination and Intensity.
- Vector (I, D, F) dates are associated with a vector defined by two polar coordinates and one value; inclination, declination and Intensity.

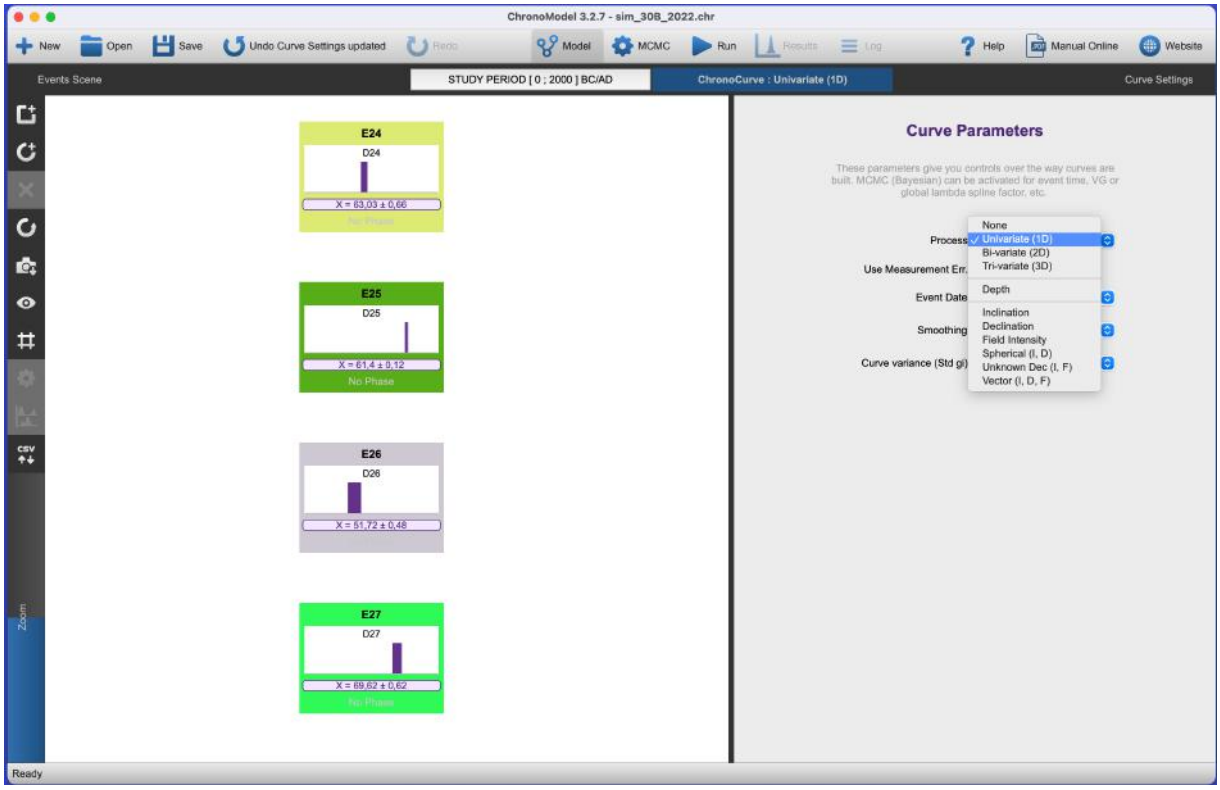


Figure 70: Possible Curve parameters

Cancels curve calculation. If position parameters have already been entered, they are retained.

8.2 Insert Event curve parameters

Once you've chosen a curve calculation mode, to assign parameters to each event, simply select an event and modify the data assigned to it. The box changes according

to the type of calculation requested and therefore the type of data to be used.

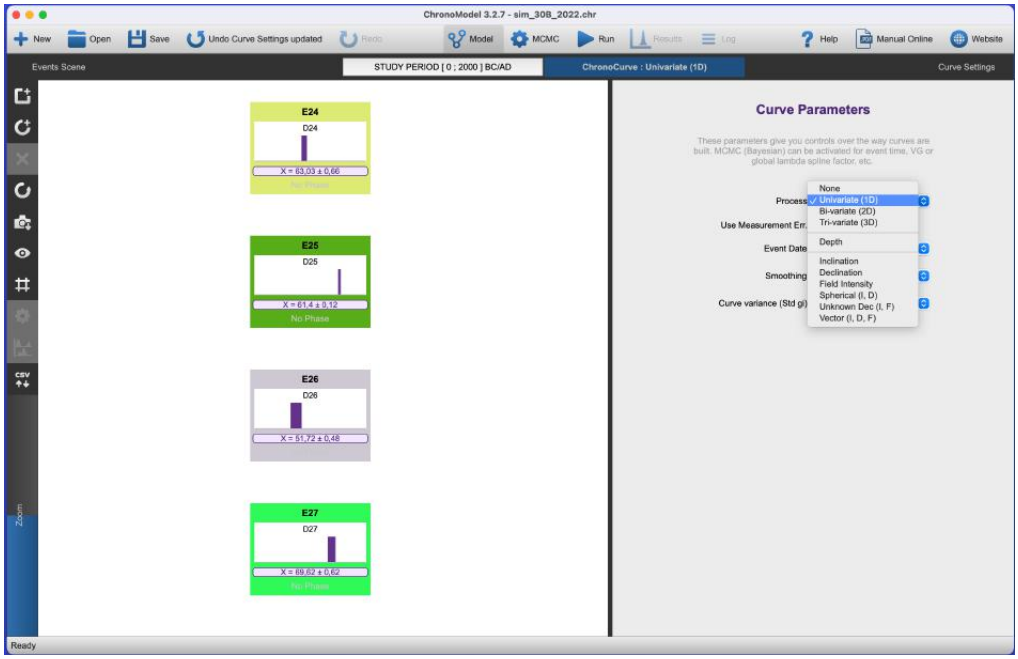


Figure 71: Parameter for univariate process

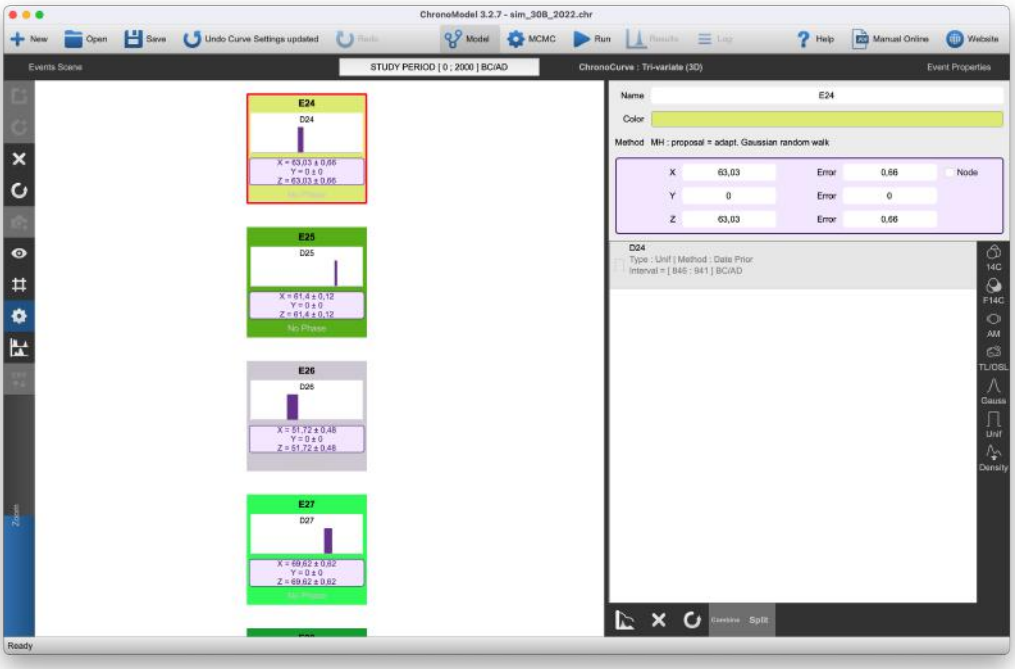


Figure 72: Event Properties windows for 3D curve

8.3 Creating a curve node

In curve mode, you can define events corresponding to curve nodes. Nodes are points through which the curve must pass. This means that there is no variance between the curve and the point. In this model, the measurement error cannot be zero.

To define a knot, check the node box in the event properties. This box is located on the right-hand side of the pink box defining event parameters on the curve.

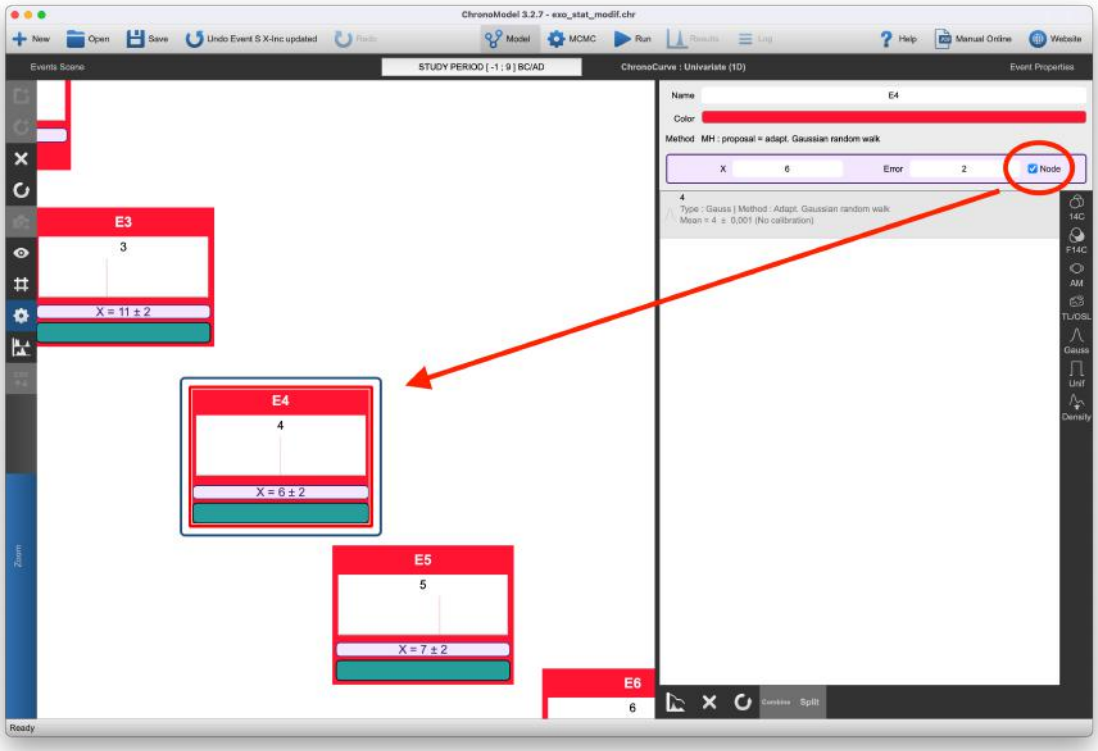


Figure 73: Node setting

Once you've defined a node, the Event (or Bound) box is surrounded by a blue line.

9 Multi-Plot of individual calibrated dates

In 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 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 button, in either PNG, JPG, BMP format or in SVG (Scalable Vector Graphics) format.

copies to clipboard either the values or the drawings.

button shows the statistics of the calibrated dates. It includes classic descriptive statistics such as mean, standard deviation, mode and quartiles, as well as credibility and HPD intervals.

Zoom offers to change the size of all drawings. Less than 100%, the text under the scale then disappears.

changes the color of all density curves.

displays scatter plot mode

Calculation of a spline in the definition given by Green and Silverman (1994). This button only appears in curve mode, i.e. ChronoCurve other than None .

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 , or click on an empty space in the Events Scene .

9.1 Drawing calibrated dates

By default, the drawing of calibrated dates is displayed. On the right, a vertical bar links the dates of the same Event. The color of the bar corresponds to the color of the Event box.

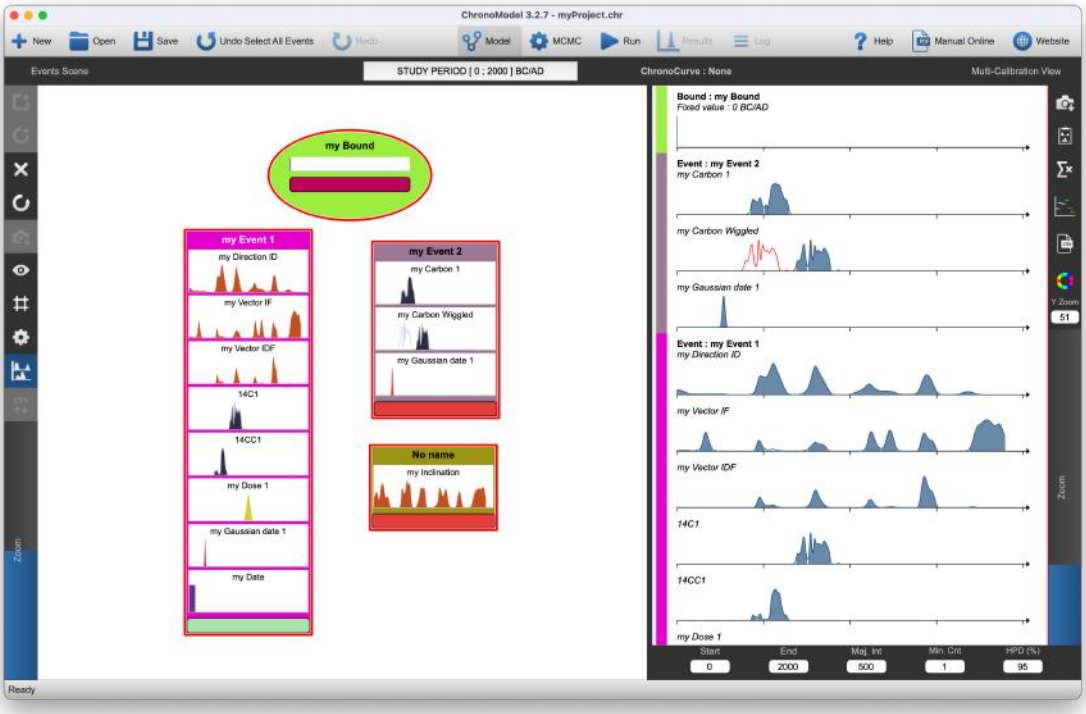


Figure 74: Multi-Calibration View and the Events scene

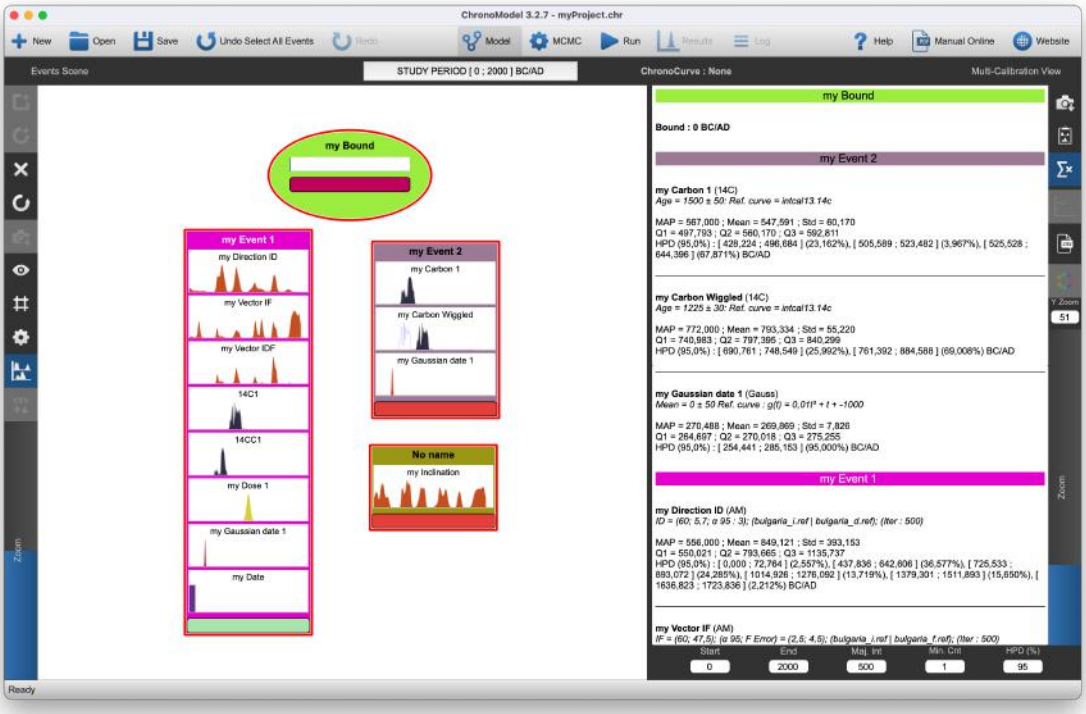


Figure 75: Multi-Calibration View and the Events scene stat

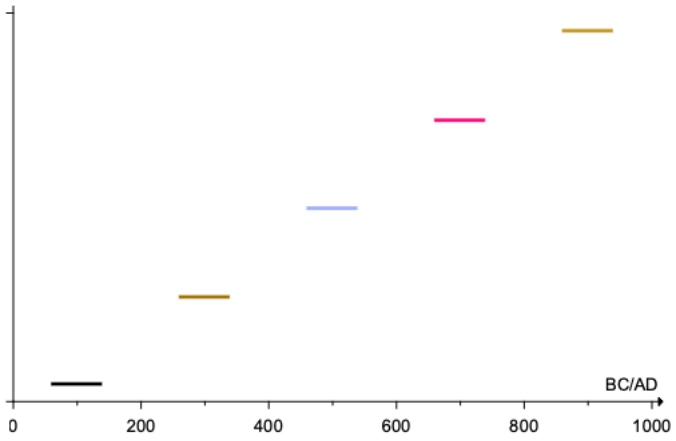
9.2 Calibrated date statistics

If it's a curve model, the Event parameters are recalled.

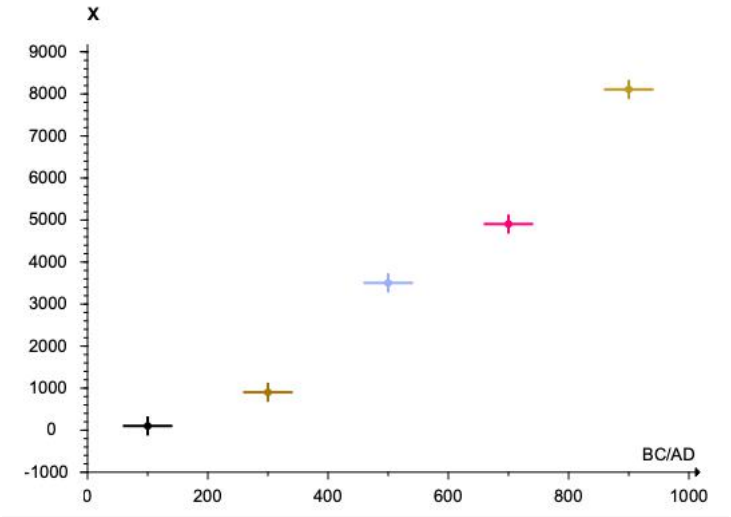
9.3 Scatter plot

By clicking on this button , this function draws the HPDs of the selected Events dates on the same graph. The position of the dates on the graph is defined as the case may be.

- If it's a chronological model, the position of the dates is defined by the position of the Event box in the Events scene.



- If it's a functional model, the position of the dates is defined by the parameter assigned to the Event. If it's a multivariate function, there are as many curves

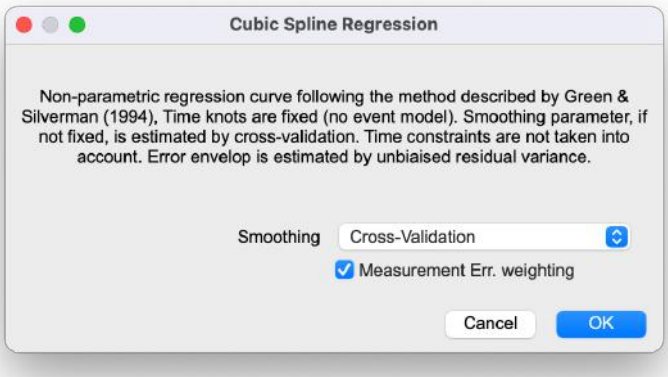


  as parameters, from one to three.

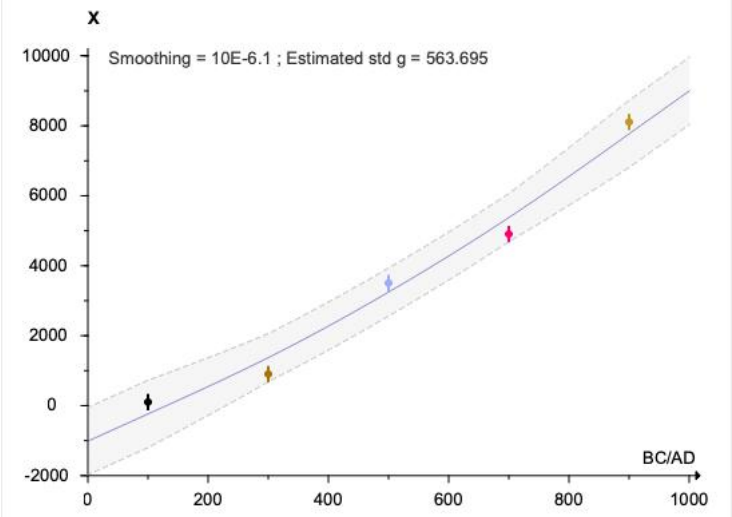
The color of the date ranges corresponds to the color of their Event.

9.4 Cubic spline regression

This button is used to run a cubic spline regression using the method described by Green and Silverman (1994). The smoothing coefficient can be evaluated by cross-validation or set by the user. The user can choose to use point error weighting to evaluate the curve. Otherwise, the points have equal weight. The error on the curve is obtained by calculating the residual variance. Note: In this calculation, the notion



of Event is ignored. Each dating corresponds to a point whose time is fixed and equal to the middle of the HPD interval at 95%. Their X, Y or Z parameters are the parameters assigned to their respective Event. In the case of multi-varied calculations, the weight used corresponds to the harmonic mean of the errors for each parameter.



9.5 Statistics export

Depending on mode

- With calibrated dates; This function creates a CSV file containing all dating statistics.
- With regression spline; Several files will be exported, one corresponding to the table of CV variations as a function of lambda, a table of GCV variations as a function of lambda, and a table for each spline curve.

9.6 Exporting density image

You may also export the image of the Events scene by clicking on the 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.

9.7 Change density color

This button changes the color of all calibrated densities.

9.8 Using the zoom

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 or by entering a value between 0 and 200 in the "Zoom" box. A double click on the scroll reset the zoom to the default value 100.

9.9 Presse-papier

By clicking on this button , the graphs created are copied to the clipboard, to be pasted into another application.

10 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

allows you to change all the parameters used in the MCMC process.

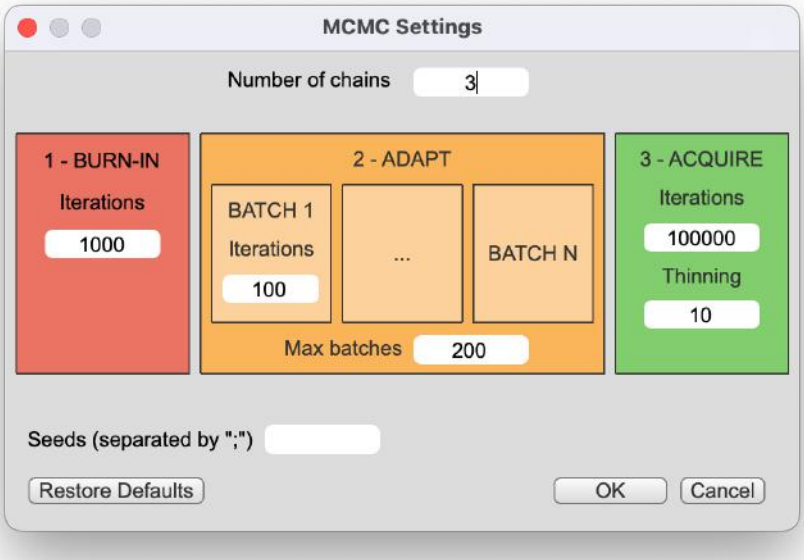


Figure 76: MCMC parameters

The button

resets all the parameters to the default values:

Number of chains = 3

BURN-IN: Iterations = 1000

ADAPTING: BATCH Iterations = 100

ADAPTING: Max batches = 200

ACQUIRING: Iterations =100000

ACQUIRING: Thinning interval = 10

Seeds = blank

11 Run

To launch an MCMC process on your model, just click on the button

. 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...
- Initializing Curves...

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

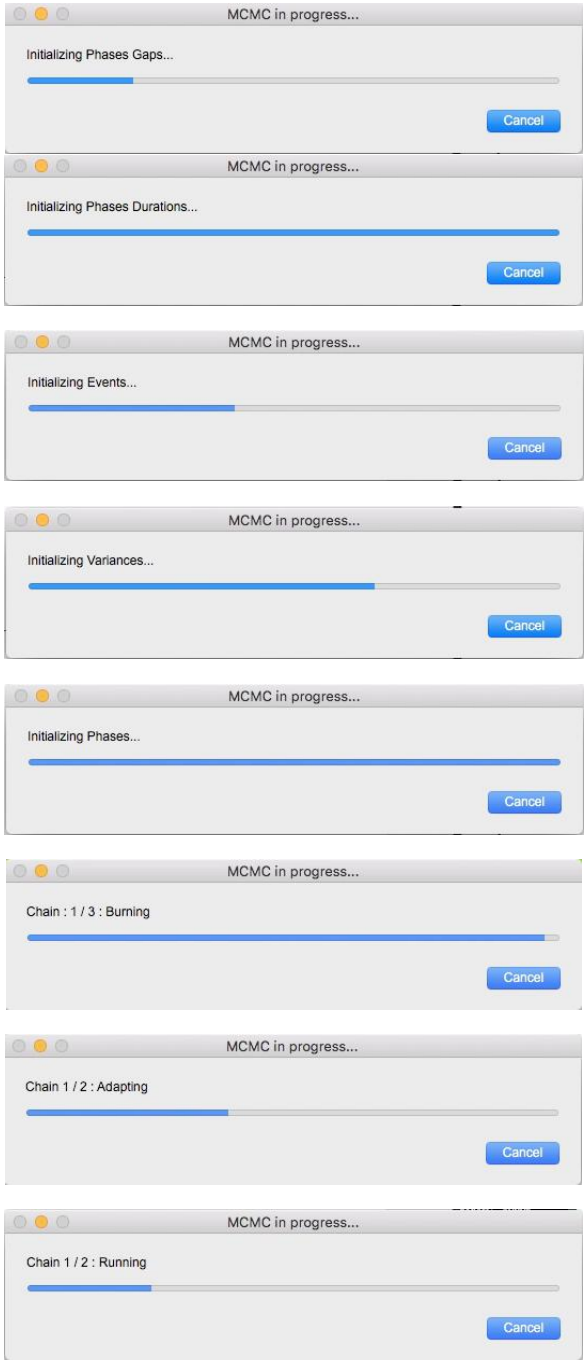


Figure 77: Run windows

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.

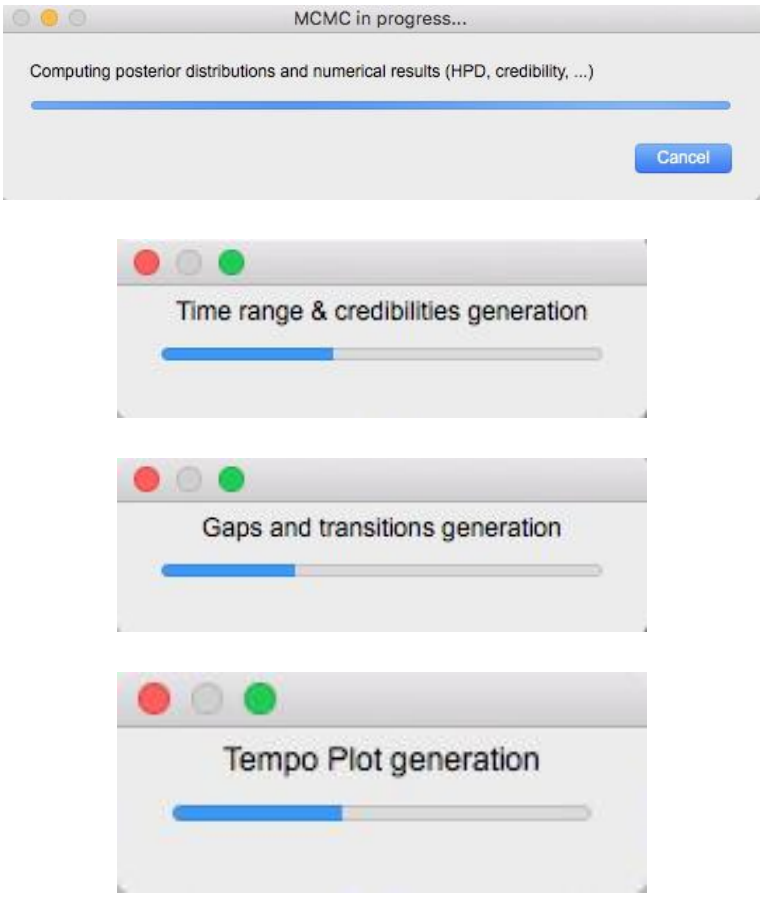


Figure 78: Post-treatment computing windows

12 Results

The "Results" window appears just after all the MCMC sampling cycles are completed and the button

is enabled.

If your model includes phases, the results are displayed directly at phase level, if it's a curve model, the curves are displayed first, otherwise the events are displayed.

12.1 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, Curves) 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.

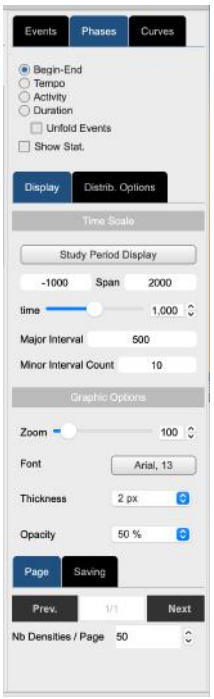


Figure 79: Main Results panel

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

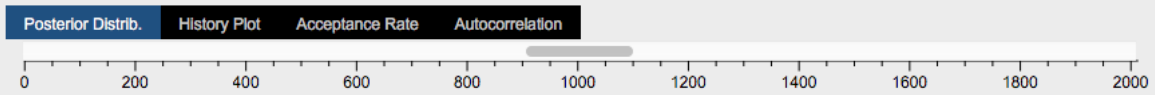


Figure 80: Type of curves tabs and ruler

Posterior Distrib. shows the marginal posterior distributions.

History Plot shows the values sampled during the MCMC process.

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 time axis. The values are reported in the Main Results Options panel (Time).

12.2 Browsing results

The upper part of the main results panel manages which results you want to see. There are three possibilities : Events , Phases or Curves . The phases tab appears if the model contains phases. Similarly, the Curve tab appears only if a curve is being modeled.

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

12.2.1 Events Tab

When you click on the Event Date tab, two radio buttons display either the Calendar Dates θ_i, or the Ind. Std. Deviations 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.

Figure 81: Events tabs

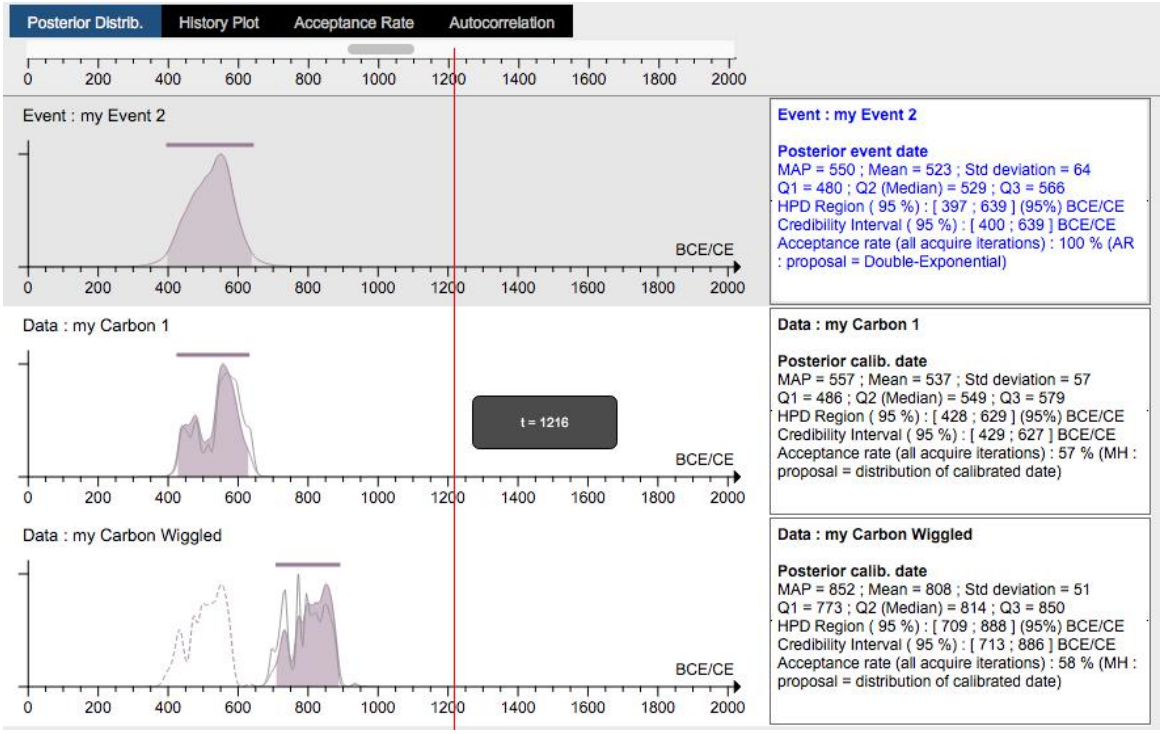


Figure 82: Events and Data drawings

12.2.2 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.

With this tab you can obtain post-treatment results for each Phase.

There are three radio buttons for three different computations.

- Begin-End gives the beginning and end of phase distributions on the same axis.
- Tempo gives the mean number of Event dates occurring before a given time

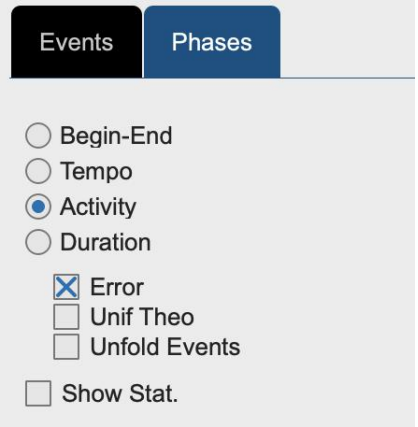


Figure 83: Phases tabs

(see Dye (2016)) and/or the Gaussian error envelope Error . There is only one type of curve Posterior Distrib. .

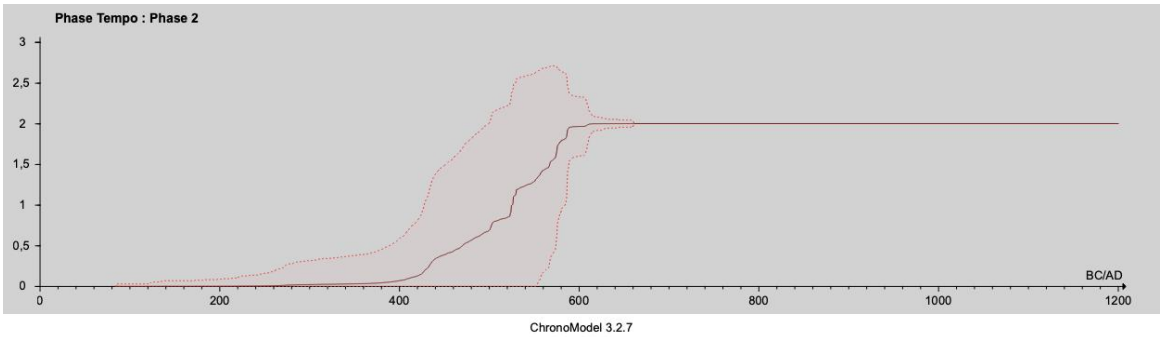


Figure 84: Example of Phase tempo plot

- Activity gives the mean number of Event dates per time unit and/or the Binomial error envelope Error . S'il est coché la case Unif Theo montre l'activité tel qu'elle serait si les évèvements provennaient d'un tirage uniformément aléatoire. En haut à droite, est affiché un score. Plus le score est grand, plus l'activité obtenue s'éloigne d'une activité produite par des évènements venant d'un phénomène aléatoire de densité uniforme, ceci en considérant l'enveloppe d'erreur sur l'activité

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

- Unfold Events is that one more checkbox, proposing to unfold all the Events belonging to the Phases and, after, to unfold the Data belonging to these Events.

- Show Stat. shows the statistical results in a box on the right of the graphs.

Figure 85: Example of Phase activity plot

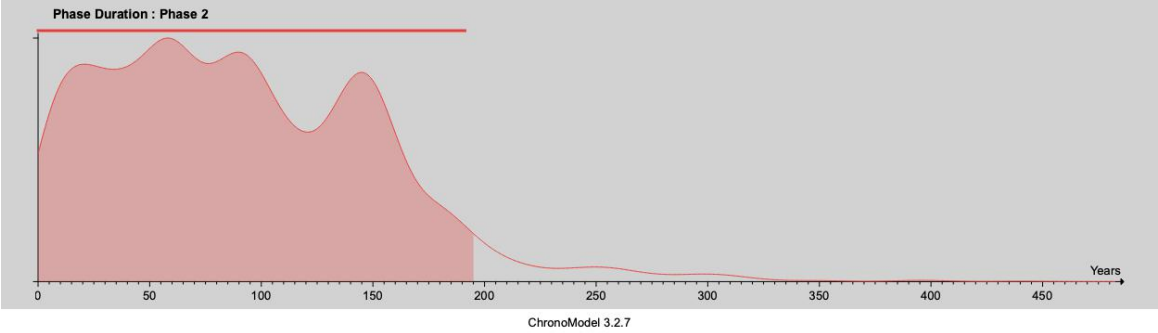


Figure 86: Example of Phase duration density

12.2.3 Curves Tab

This tab shows the results of selecting a curve model.

In the case of curves, in addition to the red line that runs over all curves, when you move the mouse a black information box indicates the coordinates in the curve reference frame. If the mouse is placed on a reference point, its name is also indicated in the box.

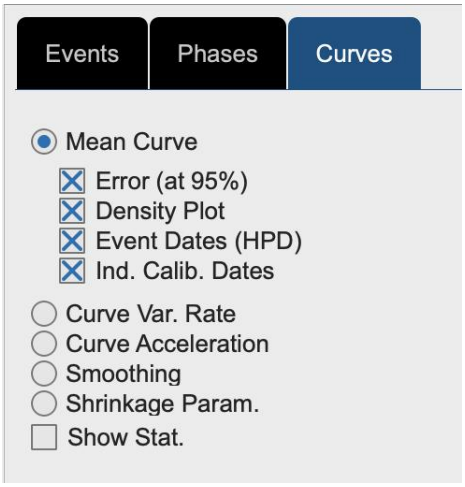


Figure 87: Curves tabs

With this tab you can obtain post-treatment results for curves.
There are five radio buttons .

- Mean Curve gives the result of the curve(s) obtained by processing the calculation.
  - Error(at 95%) draws the 95% symmetrical envelope around the mean.
  - Density Plot draws the density (map) of the curves selected.
  - Event Dates (HPD) draws bars representing the HPD obtained for each Dates.
  - Ind. Calib. Dates draws bars representing the HPD obtained for each Events Dates
- Curve Var. Rate gives the variation (derivative) of the curve(s) obtained by processing the calculation.
  - Density Plot draws the density (map) of the variation curves selected.
- Curve Acceleration gives the acceleration (second derivative) of the curve(s) obtained by processing the calculation.
- Smoothing gives the density of the smoothing parameter.
- Shrinkage Param. gives the density of the shrinkage parameter.
- Show Stat. shows the statistical results in a box on the right of the graphs.

12.3 Graphical Options

In the middle part of the Main Results panel, there are two tabs Display and Distrib. Options .

12.3.1 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

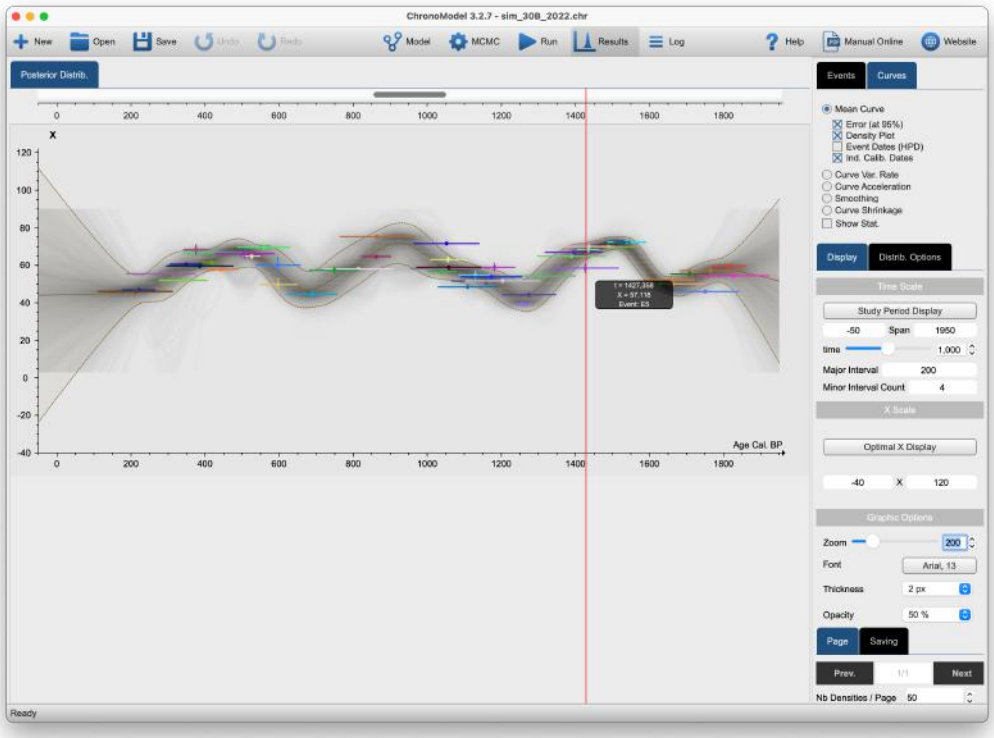


Figure 88: Mean Curve with Error Envelop

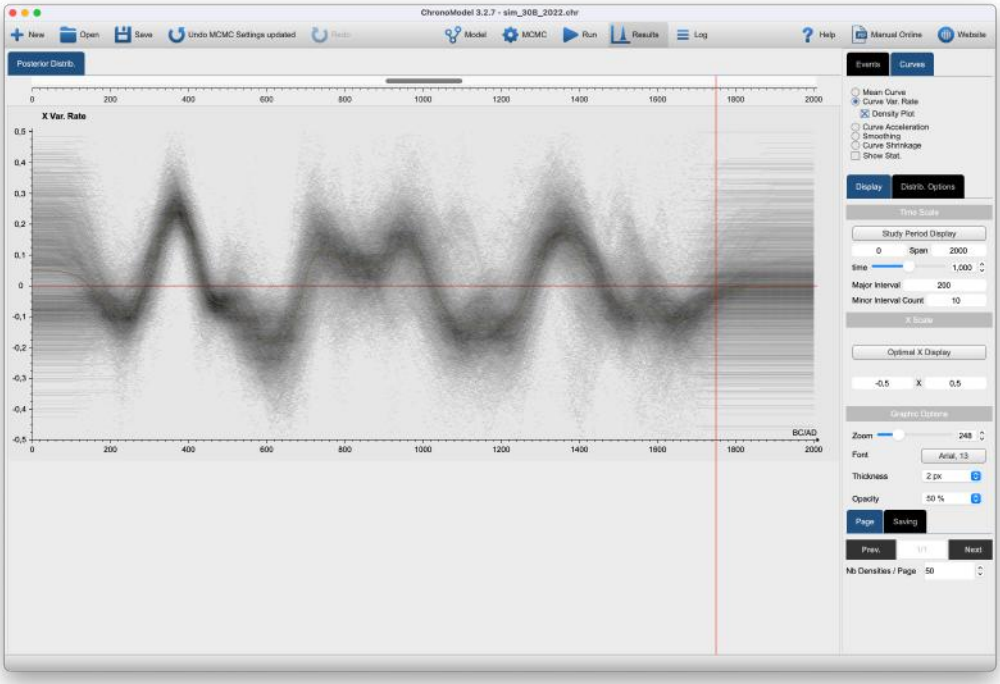


Figure 89: Curve Var. Rate

button adjusts the axis in order to see the "optimal" curve.

Two boxes on both sides of the label Time Scale allow you to set by yourself the start and the end of the axis.
Beside the time 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 5.6).

If curve mode is enabled, a field allows you to modify the ordinate scale of the curve(s). As an example, the box for a univariate X curve with X Scale label.

The Graphic Options part manages the drawing of the curves.
Beside the Zoom 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.

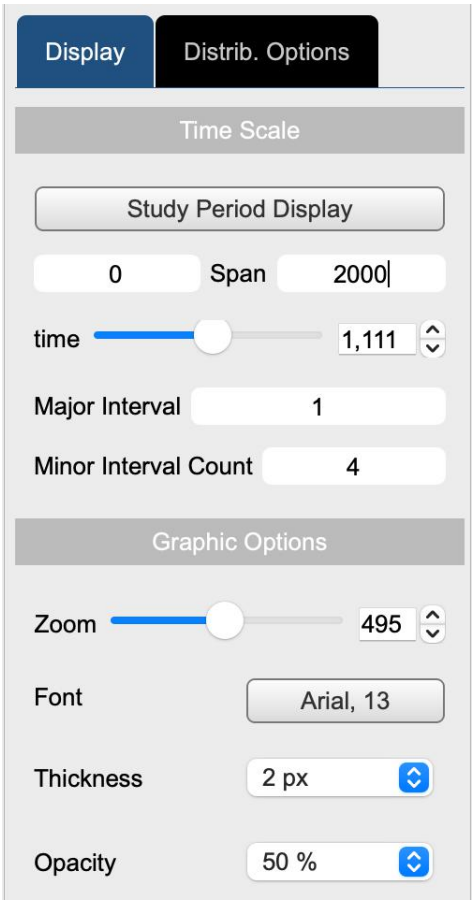


Figure 90: Display Tab

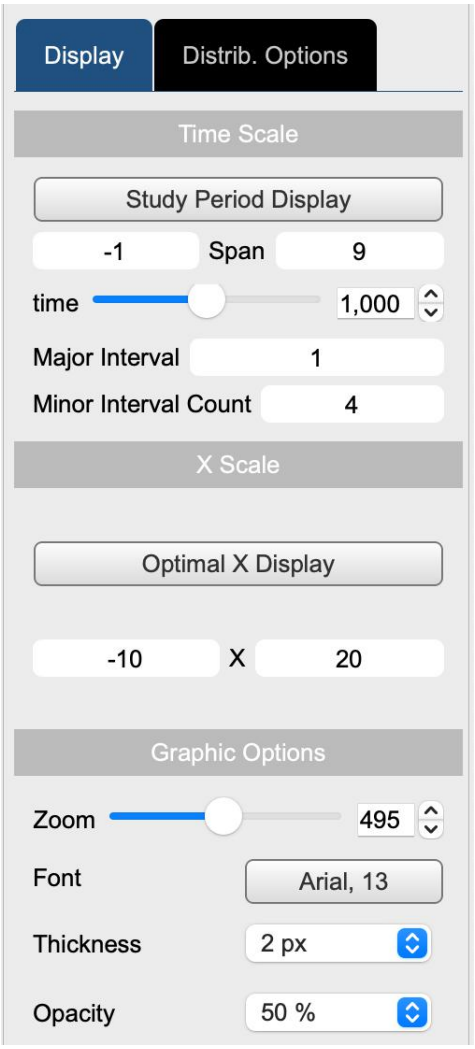


Figure 91: Display Tab

12.3.2 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.

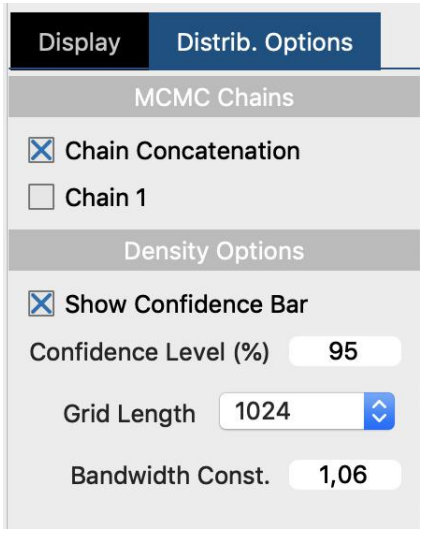


Figure 92: Distrib. Options Tab

12.4 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).

12.4.1 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 Next button changes the current page to the next page.
With the spinbox Nb Densities/Page , you can set the number of curves per page.

12.4.2 Saving

The box has either two buttons (see Figure 94) or four buttons (see Figure 95), depending on whether you have selected a graph or not. To select one or several

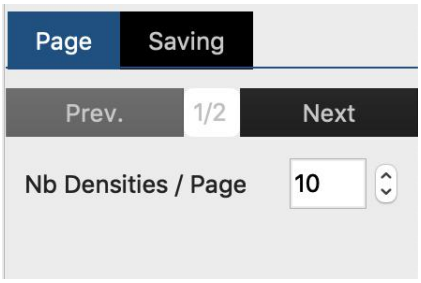


Figure 93: Distrib. Options Tab

graphs on a page, just click on them and a grey overlay with the Selected label comes over the picture.

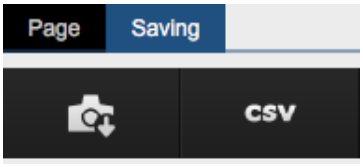


Figure 94: Saving all the page

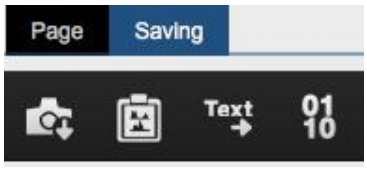


Figure 95: Saving Individual Curves

With the two-button configuration (Figure 94)

- 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 4.2.8 to set the exportation format.

- 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,

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

  `Log_Model_Description.htm`,

  `Log_MCMC_Initialization.htm`,

  `Log_Model_Adaptation.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.

In curve mode, additional files are also exported. For each parameter, there is the reference curve, the density of the curve and the density of the variation of the curve. Below is an example for parameter X.

`Curve_X_ref.csv`,

`Curve_X_Map.csv`,

`Curve_X_MapGP.csv`,

To choose the CSV format, see section 4.2.7.

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

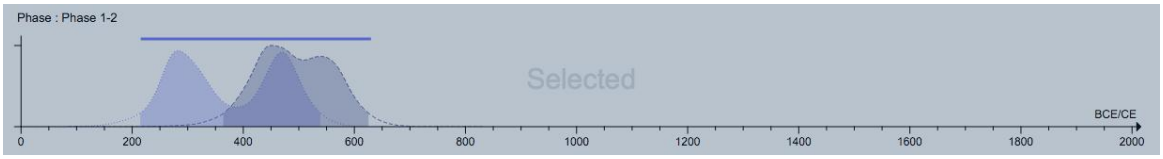


Figure 96: Example of selected drawing with overlay

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.
- Copy all the statistics of each selected item in the clipboard.
- 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?".

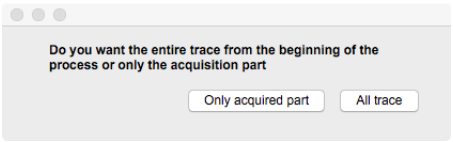


Figure 97: Example of Posterior Distribution drawing for an Event item

12.5 Marginal Posterior Distributions

In ChronoModel, the MCMC results are displayed as marginal posterior densities on the time scale (horizontal axis).

12.5.1 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 12.3.2).

- 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 5.6) is displayed in grey outline.
  If you have ticked the Unfold Data > Wiggle shifted (see Figure 81 and Figure 83, one more curve is displayed in a grey dashed line.
  If you checked Density Options > Show confidence Bar (see section 12.3.2), the credibility interval is plotted as a horizontal bar above the curves.

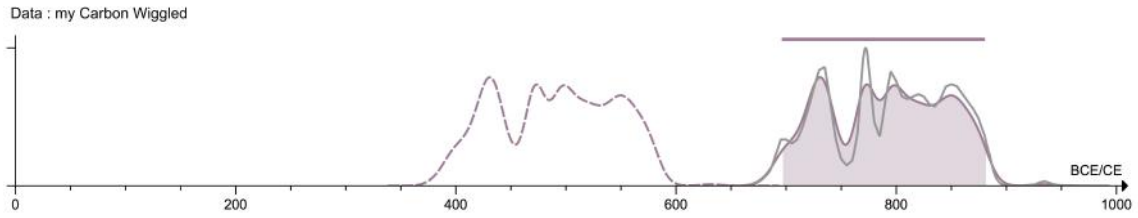


Figure 98: Example of Posterior Distribution graph for a Data item

- 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.

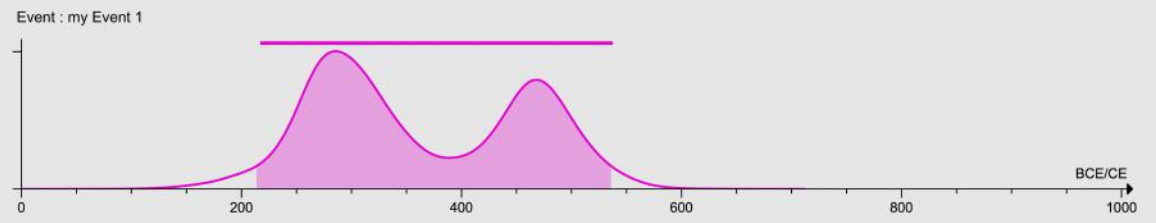


Figure 99: Example of a Posterior Distribution graph for an Event item

- 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 the calculus of the same name.
  This bar is shown if you ticked the Density Options » Show confidence Bar (see section 12.3.2)
  The color of the graph is the color of the Phase item in the Phases Scene.

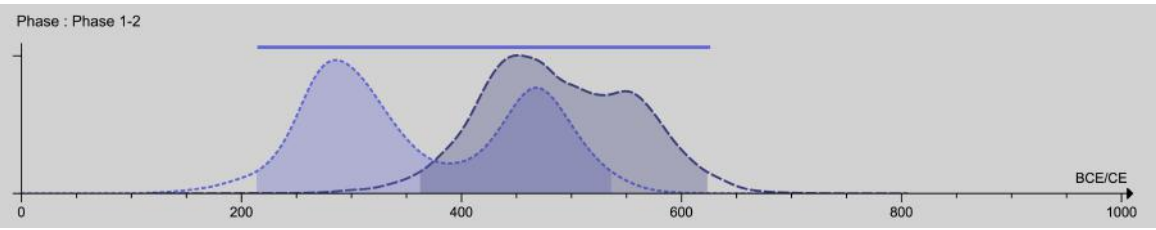


Figure 100: Example of a Posterior Distribution drawing for a Phase item

12.5.2 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 (%)

12.5.3 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.

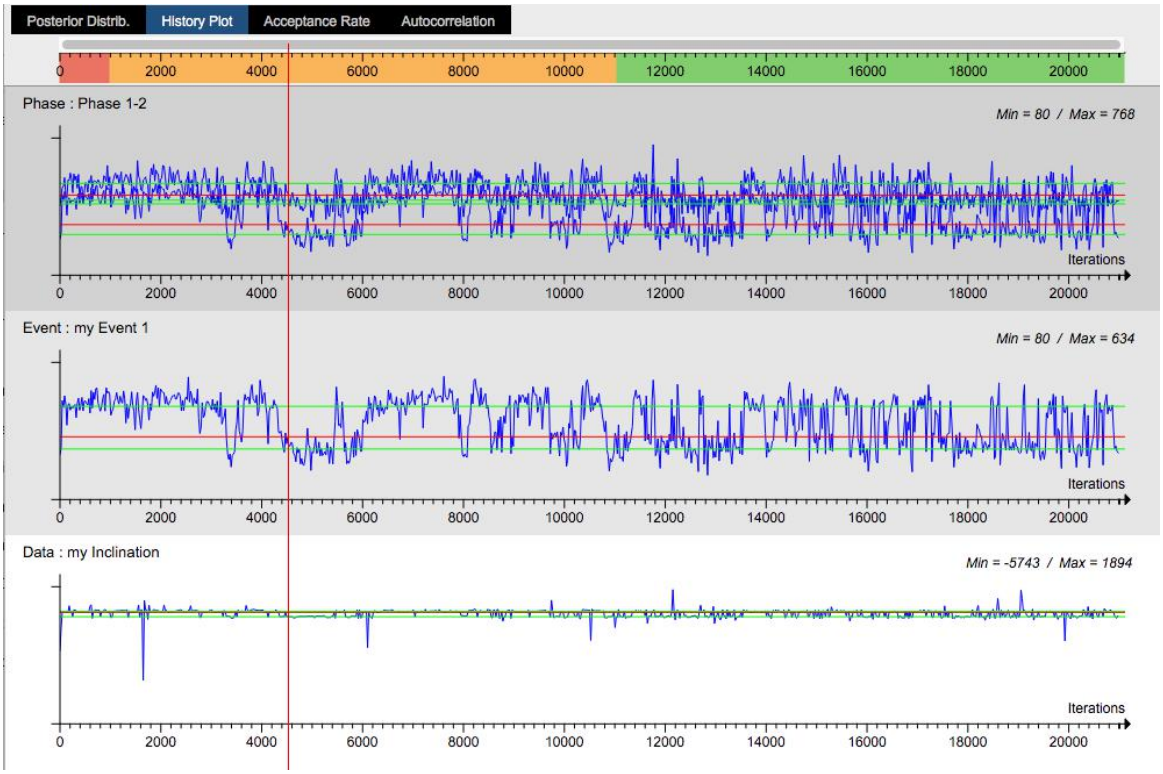


Figure 101: Example of traces for Phase, Event and Data

12.5.4 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 102: Example of Acceptance rate for Event and Data

12.5.5 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.

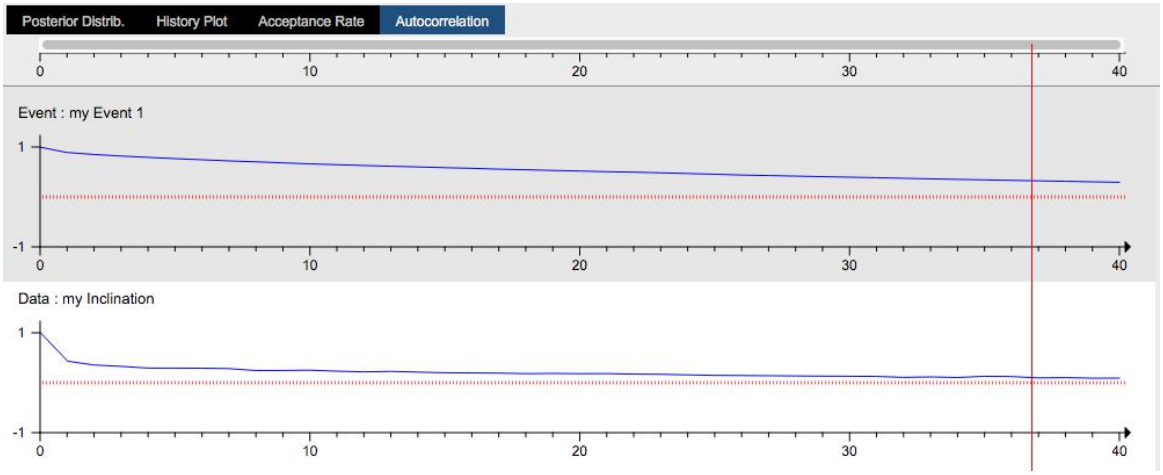
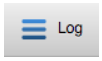


Figure 103: Example of an autocorrelation plot for Event and Data

13 Log

On the  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 Initialisation 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 MCMC Adaptation , the MCMC parameter values are displayed after the adaptation step has been completed.

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 94, these three tabs are saved in a html format. Indeed, this is useful to read results without having to open ChronoModel.

13.1 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, Phases in orange and in green for curve parameters The main organization is: The description of each Event with the description of each of the Data included. 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 104: Description

13.2 MCMC initialisation

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.

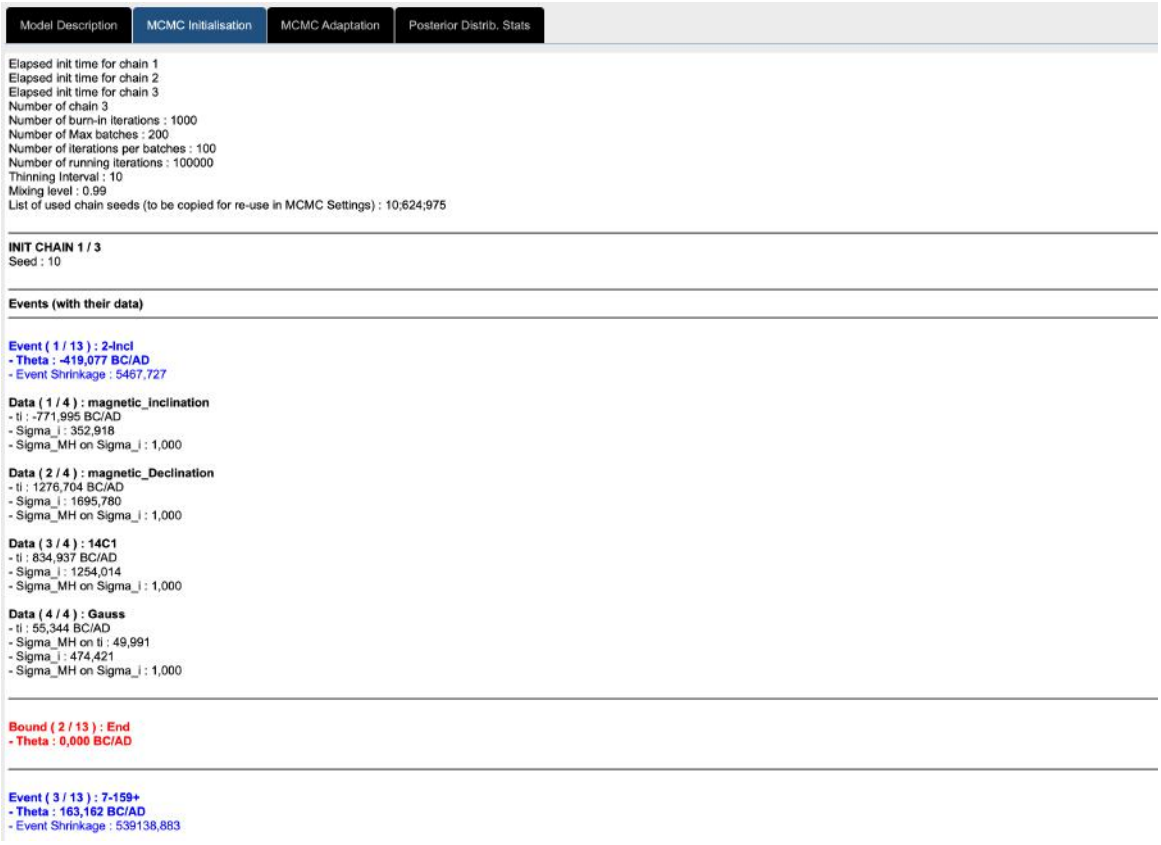


Figure 105: Log Initialisation

13.3 MCMC Adaptation

After the MCMC process Adaptation, 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. And gives the acceptance rate obtained at the end of the adaptation stage. For information, when the rate is below 44%, it is shown in red.

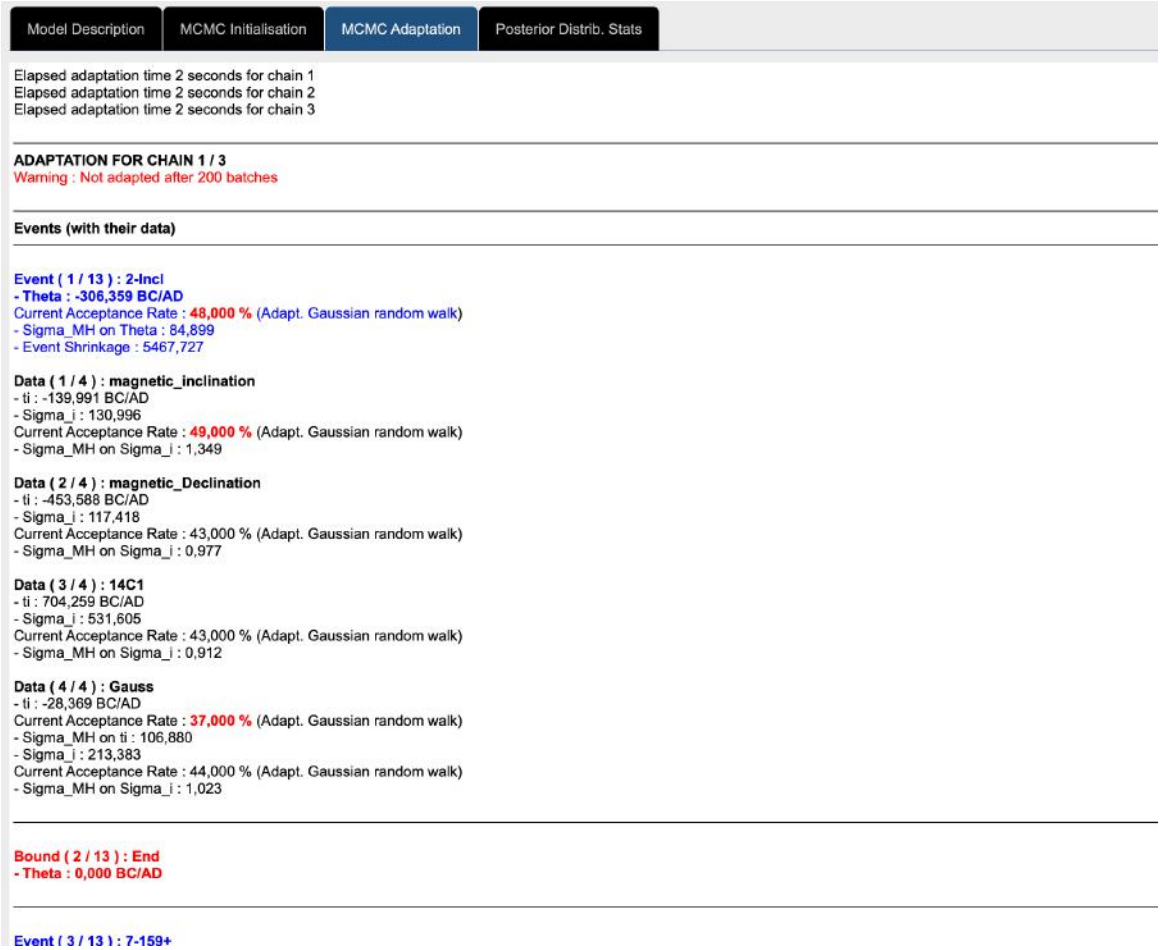


Figure 106: Log adaptation

13.4 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.

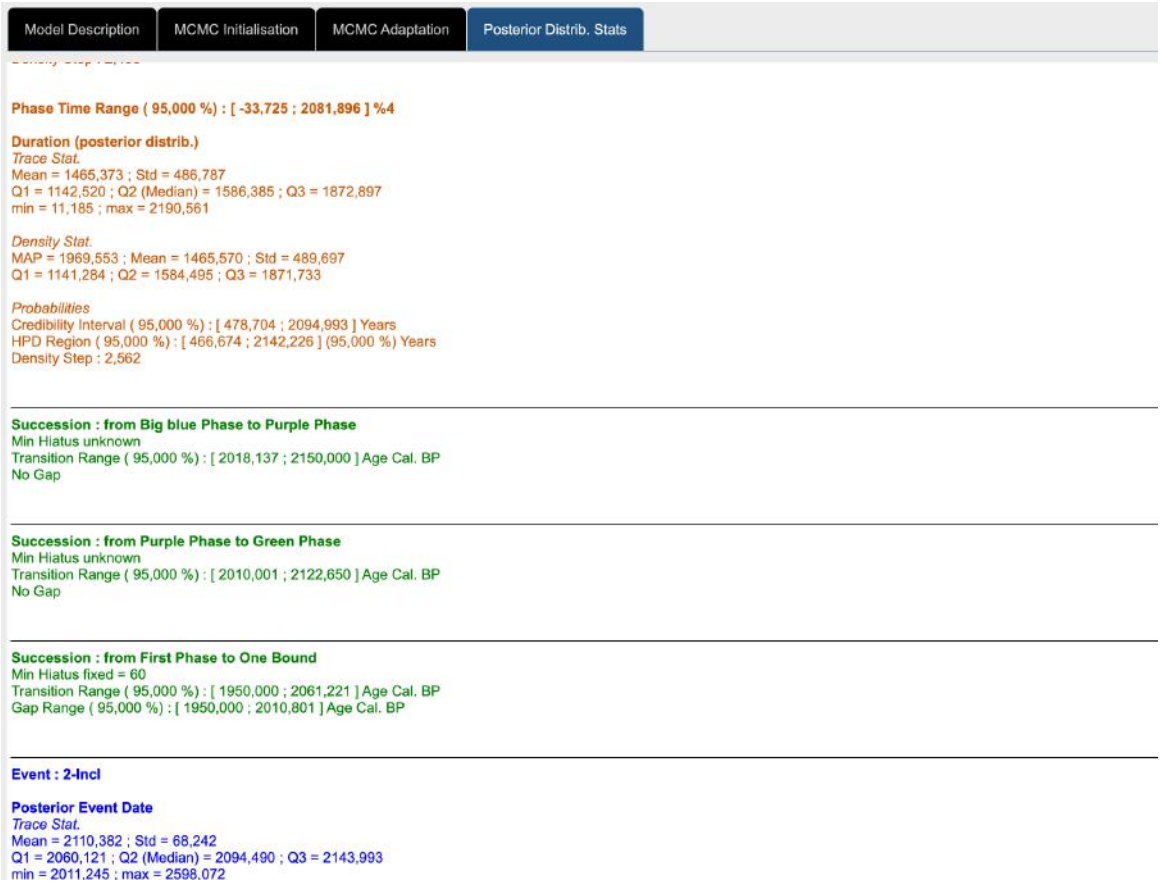


Figure 107: Log Posterior Distribution

14 Citing ChronoModel

14.1 Cite ChronoModel 3

When writing up results arising from CM 3, please cite our work by giving the reference with the URL for the software:
Lanos Ph. and Dufresne Ph. (2023). ChronoModel version 3: Software for Chronological Modeling of Archaeological Data using Bayesian Statistics. Available from: https://chronomodel.com

Citing the User manual:
Lanos Ph. and Dufresne Ph. (2024). ChronoModel version 3: User manual. Available from: https://chronomodel.com

14.2 LaTeX code for BibTeX

```
1
@Manual{chronomodelSoftwareV3-2024 ,
3     title = {ChronoModel version 3: Software for Chronological Modeling
    of Archaeological Data using Bayesian Statistics.},
      author = {Lanos, Philippe and Dufresne, Philippe},
5     year = {2024},
      url = {https://chronomodel.com},
7 }

9
@Manual{chronomodelManualV3-2024 ,
11     title = {ChronoModel version 3: User manual},
      author = {Lanos, Philippe and Dufresne, Philippe},
13     year = {2024},
      url = {https://chronomodel.com},
15 }
```

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Dye, T. (2016). Long-term rhythms in the development of Hawaiian social stratification. *Journal of Archaeological Science*, 71:1–9.

Green, P. J. and Silverman, B. W. (1994). *Nonparametric regression and generalized linear models: a roughness penalty approach*. Number 58 in Monographs on statistics and applied probability. Chapman & Hall, London ; New York, 1st ed edition.

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Hervé, G., Chauvin, A., and Lanos, P. (2013a). Geomagnetic field variations in Western Europe from 1500BC to 200AD. Part I: Directional secular variation curve. *Physics of the Earth and Planetary Interiors*, 218:1–13.

Hervé, G., Chauvin, A., and Lanos, P. (2013b). Geomagnetic field variations in western europe from 1500bc to 200ad. part ii: New intensity secular variation curve. *Physics of the Earth and Planetary Interiors*, 218:51–65.

Hogg, A. G., Heaton, T. J., Hua, Q., Palmer, J. G., Turney, C. S., Southon, J., Bayliss, A., Blackwell, P. G., Boswijk, G., Bronk Ramsey, C., Pearson, C., Petchey, F., Reimer, P., Reimer, R., and Wacker, L. (2020). SHCal20 Southern Hemisphere Calibration, 0–55,000 Years cal BP. *Radiocarbon*, 62(4):759–778.

Hogg, A. G., Hua, Q., Blackwell, P. G., Niu, M., Buck, C. E., Guilderson, T. P., Heaton, T. J., Palmer, J. G., Reimer, P. J., Reimer, R. W., Turney, C. S. M., and Zimmerman, S. R. H. (2013). SHCal13 Southern Hemisphere Calibration, 0–50,000 Years cal BP. *Radiocarbon*, 55(4):1889–1903.

Hua, Q., Barbetti, M., and Rakowski, A. Z. (2013). Atmospheric Radiocarbon for the Period 1950–2010. *Radiocarbon*, 55(4):2059–2072.

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