



HAL
open science

Analysis of archaeological phases using the CRAN package RChronoModel' A tutorial

Anne Philippe, Marie-Anne Vibet

► **To cite this version:**

Anne Philippe, Marie-Anne Vibet. Analysis of archaeological phases using the CRAN package RChronoModel' A tutorial. 2016. hal-01347895v1

HAL Id: hal-01347895

<https://hal.science/hal-01347895v1>

Preprint submitted on 21 Jul 2016 (v1), last revised 20 Sep 2018 (v5)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Analysis of archaeological phases using the CRAN package RChronoModel' A tutorial

Anne Philippe, Marie-Anne Vibet
Laboratoire Jean Leray, Université de Nantes, ANJA Inria-Rennes & Centre Henri Lebesgue
`anne.philippe@univ-nantes.fr`

July 20, 2016

Abstract

The R package 'RChronoModel' gives a list of functions developed in order to treat the output of the MCMC algorithm computed with the softwares ChronoModel or Oxcal, especially regarding phases. We give a practical introduction to the package 'RChronoModel' using published data and comment the statistical results. We also introduce our new web application that allows users to take advantages of all these R functions without having to know R.

1 Introduction

Bayesian inference is a probabilistic estimation method, in the sense that the information on the estimated parameters is given by a probability distribution called posterior probability. Usually the analytic expression of the posterior distribution is not easily computable. However, inferences may be drawn using a sample from the posterior density. More precisely, it is possible to compute a Markov chain whose target distribution is the posterior distribution. Indeed, Markov chain Monte Carlo (MCMC) algorithms provide a way of drawing samples from the joint posterior distribution in high-dimensional Bayesian models.

Chronomodel (see [3, 5]) or Oxcal (See [4, 1]) are two softwares which provide Bayesian statistical modeling for constructing archaeological chronologies using dating measurements. Both softwares return the samples of all parameters (see section 4 for the details). From these MCMC samples we construct

- time intervals to characterize archaeological phases or periods. They cover the beginning and the end of the phase/period with fixed posterior probability (e.g. 95 %, 68 % ...) .
- time intervals to characterize the transition between two successive phases or periods. They cover the end of one phase and the beginning of the next phase/period in the succession with fixed posterior probability (e.g. 95 %, 68 % ...) .
- testing procedure to check the presence of a gap (hiatus) between two successive phases or periods.

The CRAN package 'RChronoModel' provides a list of functions for calculating these statistics from the Markov Chains simulated by ChronoModel or by Oxcal. In this tutorial, we give a practical introduction to the use of these R functions on data published by Bosch et al. [2]. This tutorial illustrates the use of the functions of RChronoModel for people who are familiar with R software. For the others, however, a web application has been also developed in order to take advantages of these functions without having to know R. The details of the application are given in the last section.

2 Statistical aspects

The construction of a chronology is not only a matter of estimation of calendar dates τ_1, \dots, τ_n but also the characterization of historical/geological periods called archaeological phases. The estimation of the phase can only be done from the dated events associated to this phase.

A phase is commonly defined by two parameters : its beginning and its end. Two different approaches are considered in order to estimate the beginning and the end of a phase.

- the Bayesian model implemented in Oxcal. The beginning and the end are included as additional parameters (denoted α and β) of the Bayesian model.
- the Bayesian model implemented in Chronomodel. It does not integrate a modelling of the phase, indeed only a post-processing step is suggested. The beginning (resp. the end) is estimated by the minimum (resp. the maximum) of the dates of the events included in the phase.

Hereafter we assume that MCMC samples from the joint posterior distribution of all the parameters are available (using for instance ChronoModel or Oxcal).

In the following, let's characterize a phase P by a collection of dates, τ_i for $i \in I$ where I is a subset of $\{1, \dots, n\}$, gathered on some common criteria and, for modelling done with Oxcal, two additional parameters α, β where α (resp. β) corresponding to the beginning (resp. the end) of the phase.

2.1 Range time interval and transition

We propose now to characterize a phase using an time interval called a time range interval.

Definition 1. *The $100(1 - \gamma)\%$ Phase time range is the shortest interval $[a, b] \subset T$ such that*

1. **Chronomodel**

$$P((\tau_i \in]a, b[, \forall i \in I) | \mathcal{M}) = 1 - \gamma \quad (1)$$

2. **Oxcal**

$$P((\alpha \in [a, b], \beta \in [a, b], \tau_i \in]a, b[, \forall i \in I) | \mathcal{M}) = 1 - \gamma \quad (2)$$

where I is a subset of $\{1, \dots, n\}$, n the total number of calendar dates, and \mathcal{M} denotes the set of measurements coming from dating methods.

Oxcal By construction of the prior distribution on α and β , the equation (2) can be rewrite as

$$P(a \leq \alpha \leq \beta \leq b | \mathcal{M}) = 1 - \gamma \quad (3)$$

Chronomodel If we denote $\alpha = \min(\tau_i, \forall i \in I)$ and $\beta = \max(\tau_i, \forall i \in I)$ the estimation of the beginning and the end of the phases in Chronomodel case. The equation (1) can be also rewrite of the form (3).

Remark 1. *To simply the exposition we use hereafter the same notation for the beginning and the end of the phases even if the construction of these variables are very different in both cases.*

The construction of the time range interval depends on the joint posterior distribution of (α, β) . The collection of intervals satisfying (3) is described by this set of intervals :

$$\{[a(\epsilon); b(\epsilon)], \quad \epsilon \in [0, \gamma]\}$$

where

- $a(\epsilon) = F_{\alpha}^{-}(\epsilon | \mathcal{M})$ with $F_{\alpha}^{-}(\cdot | \mathcal{M})$ is the quantile function of the posterior distribution of α
- $b(\epsilon) = F_{\beta}^{-}(\frac{1-\gamma}{1-\epsilon} | \alpha \geq a(\epsilon), \mathcal{M})$ with $F_{\beta}^{-}(\cdot | \alpha \geq a(\epsilon), \mathcal{M})$ is the quantile function of the conditional distribution of β given $\alpha \geq a(\epsilon)$ and \mathcal{M} .

Indeed, $\alpha \leq \beta$ happens almost surely, so we have

$$\begin{aligned} P(a(\epsilon) \leq \alpha \leq \beta \leq b(\epsilon) | \mathcal{M}) &= P(a(\epsilon) \leq \alpha, \beta \leq b(\epsilon) | \mathcal{M}) \\ &= P(\beta \leq b(\epsilon) | a(\epsilon) \leq \alpha, \mathcal{M})P(a(\epsilon) \leq \alpha | \mathcal{M}) \\ &= \frac{1-\gamma}{1-\epsilon}(1-\epsilon) \end{aligned}$$

The last equality comes from the definition of $a(\epsilon)$ and $b(\epsilon)$. Therefore the shortest interval is obtained by taking $[a(\epsilon^*), b(\epsilon^*)]$ where

$$\epsilon^* = \operatorname{argmin}_{\epsilon \in [0, \gamma]} (b(\epsilon) - a(\epsilon))$$

In practice, the values of $a(\epsilon)$ and $b(\epsilon)$ are estimated by the empirical quantiles calculated on the MCMC outputs. Let $(\alpha(t), \beta(t))_{t=1, \dots, N_{MCMC}}$ the MCMC sample corresponding to the posterior distribution of (α, β) . $a(\epsilon)$ is estimated by the empirical quantile of the sample $\{\alpha(1), \dots, \alpha(N_{MCMC})\}$ (sample corresponding to the marginal posterior distribution of α). $b(\epsilon)$ is estimated by the empirical quantile of $\{\beta(t), t \in T\}$ where $T = \{j | \alpha(j) \geq \epsilon\}$

2.2 Testing procedure for gap/hiatus

Definition 2. *Consider a succession of two phases, P_1 and P_2 , characterized by α_i (resp. β_i), $i = 1, 2$, its beginning (resp. its end). The $100(1 - \gamma)\%$ Phase gap between these successive phases (if it exists) is the longest interval $[a, b] \subset T$ such that*

$$P(\beta_1 \leq a \leq b \leq \alpha_2 | \mathcal{M}) = 1 - \gamma \quad (4)$$

The first step consists in the construction of all the couples $a(\epsilon), b(\epsilon)$ such that

$$P(\beta_1 \leq a(\epsilon), b(\epsilon) \leq \alpha_2 | \mathcal{M}) = 1 - \gamma$$

where

- $a(\epsilon) = F_{\beta_1}^-(1 - \epsilon | \mathcal{M})$ and $F_{\beta_1}^-(\cdot | \mathcal{M})$ is the quantile function of the posterior distribution of β_1
- $b(\epsilon) = F_{\alpha_2}^-(\frac{\gamma - \epsilon}{1 - \epsilon} | \beta_1 < a(\epsilon), \mathcal{M})$ and $F_{\alpha_2}^-(\cdot | \beta_1 < a(\epsilon), \mathcal{M})$ is the quantile function of the conditional distribution of α_2 given $\beta_1 < a(\epsilon)$ and \mathcal{M} .

Indeed

$$\begin{aligned} P(\beta_1 \leq a(\epsilon), b(\epsilon) \leq \alpha_2 | \mathcal{M}) &= P(\beta_1 \leq a(\epsilon) | \mathcal{M})P(b(\epsilon) \leq \alpha_2 | \beta_1 \leq a(\epsilon), \mathcal{M}) \\ &= (1 - \epsilon)(1 - \frac{\gamma - \epsilon}{1 - \epsilon}) = 1 - \gamma \end{aligned}$$

Testing procedure : If the set $E = \{\epsilon | a(\epsilon) < b(\epsilon)\}$ is empty, then we conclude that, with probability $1 - \gamma$, no gap exists between these successive phases. Otherwise, the gap interval is the longest interval $[a(\epsilon^*), b(\epsilon^*)]$ where

$$\epsilon^* = \operatorname{argmax}_{\epsilon \in E} (b(\epsilon) - a(\epsilon))$$

2.3 Transition between successive phases

We can also evaluate the transition between two successive phases. The transition interval is the shortest interval that covers the end of the oldest phase and the beginning of the youngest phase.

From a computational point of view this is equivalent to the phase time range calculated between the end of the oldest phase and the beginning of the youngest phase.

Definition 3. Consider a succession of two phases, P_1 and P_2 , characterized by α_i (resp. β_i), $i = 1, 2$, its beginning (resp. its end). The $100(1 - \gamma)\%$ transition interval is the shortest interval $[a, b] \subset T$ such that

$$P(a \leq \beta_1 \leq \alpha_2 \leq b | \mathcal{M}) = 1 - \gamma \quad (5)$$

3 The example of Ksar Akil

At Ksâr 'Akil (Lebanon), a deep Paleolithic stratigraphic sequence was investigated in order to establish the chronology of the site (See Bosch et al. [2]). This stratigraphic sequence included Initial Upper Paleolithic (IUP), from layer XXV (the bottom of the sequence) to layer XXI, Ahmarian, from layer XX to layer XIV, Upper Paleolithic (UP), from layer XV to layer VI, and Epi-Paleolithic (EPI), from layer V to layer I. In addition, 16 shell ornaments were found throughout the stratigraphy and dated by AMS radiocarbon technique.

The aim of this modelling was to establish the chronology of the succession of phases : IUP, Ahmarian, UP and EPI using these 16 radiocarbon dates and the information coming from the stratigraphy.

For the modelling with ChronoModel, the study period was set to -50 000 to -25 000. Target events were the death of the shells. Each event was then associated with one radiocarbon date. Each layer was modelled by a phase including all events (death of shells) found within each layer in the stratigraphy. Then IUP, Ahmarian, UP and EPI phases gathered all the events of the layers included in these phases.

The post-processing of the Markov Chains simulated by ChronoModel were then extracted to illustrate the use of RchronoModel. This procedure is described in Section 4.

4 Extracting the MCMC sample of the joint distribution

4.1 From ChronoModel

Once your modeling is done and once the RUN command is launched, you may save all MCMC samples in format BC/AD.

To do that, use **CSV Results** on the right hand side of the window in the Results tab (See figure 1). Several CSV files will be created : a file called "events.csv" containing the MCMC samples of all events, a file called "phases.csv" containing all parameters (beginning and end) of phases if at least one phase is modelled, and a file per phase (if any) containing the MCMC samples of the parameters of the phase and all events included in it.

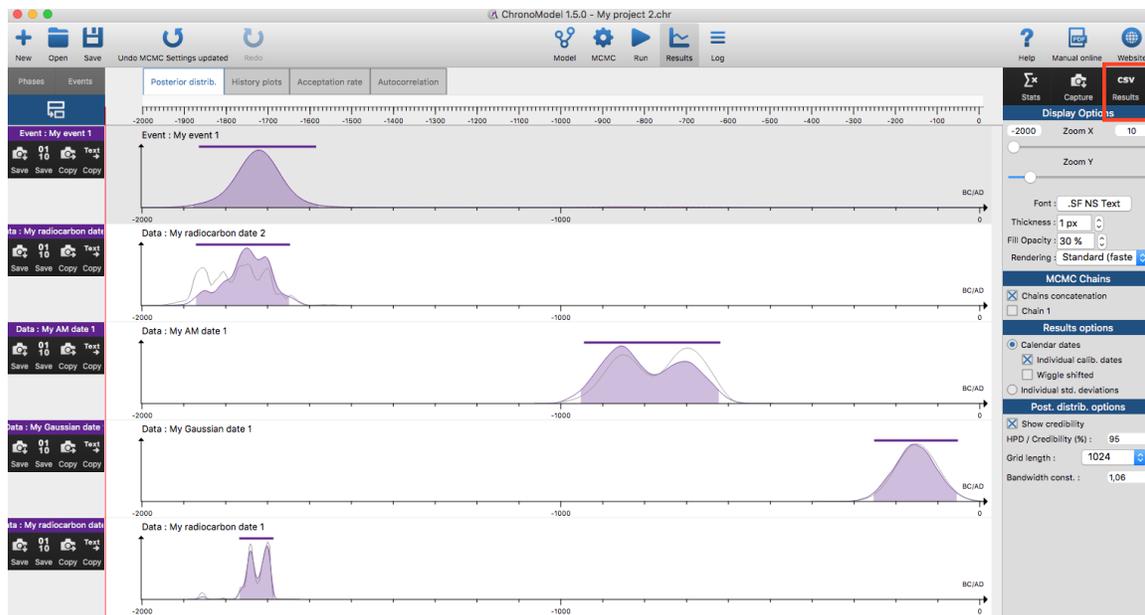


Figure 1: ChronoModel interface showing the results of a modelling.

4.2 From Oxcal

Once your modeling is done, add the `MCMC_Sample` command to your script.

```
MCMC_Sample([Name], [Interval], [Max]) ... ;
```

allows all of the MCMC samples to be saved to a file (default is `MCMC_Sample.csv`) at defined intervals and with a maximum number of samples taken (default 1000); the file can be found as a Document

5 The use of RChronoModel

5.1 Installing the package 'RChronoModel'

When R is launched, you need to install (only the first time) the package 'RChronoModel' using the following code:

```
1 install.packages('RChronoModel', dependencies = TRUE)
```

programmesR/InstallingPackage.R

Then the first step is to load the library:

```
1 library(RChronoModel)
```

programmesR/loadPackage.R

and then to define your working directory. Usually, the working directory is the directory where the data exported from ChronoModel is saved.

For example, if the data are stocked in a directory called "ChronoModel/data" on the desktop of the computer, the working directory will be changed using the following command:

```
1 setwd("~/Desktop/ChronoModel/data")
```

programmesR/SettingWorkingDirectory.R

5.2 Importing data into R software

To import the data file into R, you may use `ImportCSV` function. For CSV files extracted from ChronoModel software, there is no need to specify any other parameters than the name of the file (and the path to it). Otherwise, you may change the specification after "sep=" and "dec=".

```
1 Phases <- ImportCSV("phases.csv", sep=",", dec=".", comment.char="#")
2 # equivalent to
3 Phases <- ImportCSV("phases.csv")
4
5
6 attach(Phases)
```

programmesR/IncludingData.R

The parameter "`comment.char=`" is used to define how comments are written in the file to be imported. Comments of all csv file generated by ChronoModel are specified by '#'.

The sixth line of the code makes all objects of the database "Phases" accessible by simply giving their names without having to recall the dataset of origin. For instance the two following lines give the same result.

```
1 summary(Phases$Ahmarian.alpha)
2 summary(Ahmarian.alpha)
```

programmesR/AttachExample.R

The output of the R console is the following:

```
> summary(Phases$Ahmarian.alpha)
  Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
-45920 -41640  -41420  -41450  -41220  -40240
> summary(Ahmarian.alpha)
  Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
-45920 -41640  -41420  -41450  -41220  -40240
```

This will be usefull in the following sections.

5.3 Examining an archeological phase

A phase is characterised by its beginning and its end. From the output of the MCMC algorithm, one can estimate the duration of the phase as the value of the end - beginning at each iteration. One can also estimate the phase time range as the shortest interval that contains the beginning and the end of the phase at a given confidence level (See section 2 for more details).

One may be interested in summary statistics of all posterior distributions related to a phase. To do that, there are two different ways.

```
1 # The beginning of the phase
2 MarginalStatistics(Ahmarian.alpha)
3 # The end of the phase
4 MarginalStatistics(Ahmarian.beta, level = 0.90)
5 # The duration of the phase
6 MarginalStatistics(Ahmarian.beta-Ahmarian.alpha)
7
8 ## OR EQUIVALENTLY
9 # Global statistics of a phase
10 PhaseStatistics(Ahmarian.alpha, Ahmarian.beta)
11
12 # The phase time range
13 PhaseTimeRange(Ahmarian.alpha, Ahmarian.beta)
```

programmesR/SummaryStatistics.R

Let's examine the results of the line 10. The output of the R console is the following:

```
> PhaseStatistics(Ahmarian.alpha,Ahmarian.beta)
              Beginning      End Duration
mean          -41447.00 -38141.00  3306.00
MAP            -41416.00 -38150.00  3290.00
sd              335.00   412.00   526.00
Q1             -41639.00 -38396.00  2958.00
median         -41417.00 -38146.00  3285.00
Q2             -41221.00 -37898.00  3631.00
level          0.95      0.95      0.95
CredibleInterval Inf -42134.00 -38964.00  2292.00
CredibleInterval Sup -40857.00 -37317.00  4351.00
HPDRInf        -42080.00 -38971.00  2264.00
HPRDSup        -40778.00 -37320.00  4331.00
```

PhaseStatistics() results in a matrix of several summary statistics according to the marginal posterior density of the beginning, the end and the duration of the phase Ahmarian. The default confidence level is 0.95 but may be changed as shown in line 4. Lines 1 to 6 would give similar results (not shown).

Results corresponding to the line 13 give the endpoints of the time range of the phase Ahmarian and recall the given confidence level. The output of the console is

```
> PhaseTimeRange(Ahmarian.alpha, Ahmarian.beta)
      level TimeRangeInf TimeRangeSup
      0.95   -42210.62   -37319.37
```

To draw a plot of the marginal posterior density of the beginning and the end of a phase on a same graph, use the following lines:

```
1 # Plot of the densities
2 PhasePlot(Ahmarian.alpha, Ahmarian.beta, title ="Marginal posterior densities of
   Phase Ahmarian")
3
4 # Plot of the duration of a phase
5 PhaseDurationPlot(Ahmarian.alpha, Ahmarian.beta, title ="Duration of Phase
   Ahmarian")
6
7 # Plot of the densities of a phase in black and white (result not shown)
8 PhasePlot(Ahmarian.alpha, Ahmarian.beta, level = 0.90, title ="Marginal posterior
   densities of Phase Ahmarian", colors = FALSE)
```

programmesR/PhasePlot.R

Figure 2 displays the result of line 2. Marginal posterior densities of the beginning and the end of phase Ahmarian are presented with the shortest credible interval at the desired level (default = 95 %) and their mean value. The curves, the a solid line and a dot of corresponding color represent respectively the marginal posterior density, the shortest credible interval and the mean value of the parameter (beginning or end). In addition, the time interval of the phase at the desired level (default = 95 %) is also presented by a solid line at the top of the picture.

Figure 3 displays the result of line 5. The marginal posterior density of the duration of the phase is drawn with the shortest credible interval and the mean value.

By default, the confidence level is fixed at 0.95 and graphs are in colors but these details may be changed. See line 8.

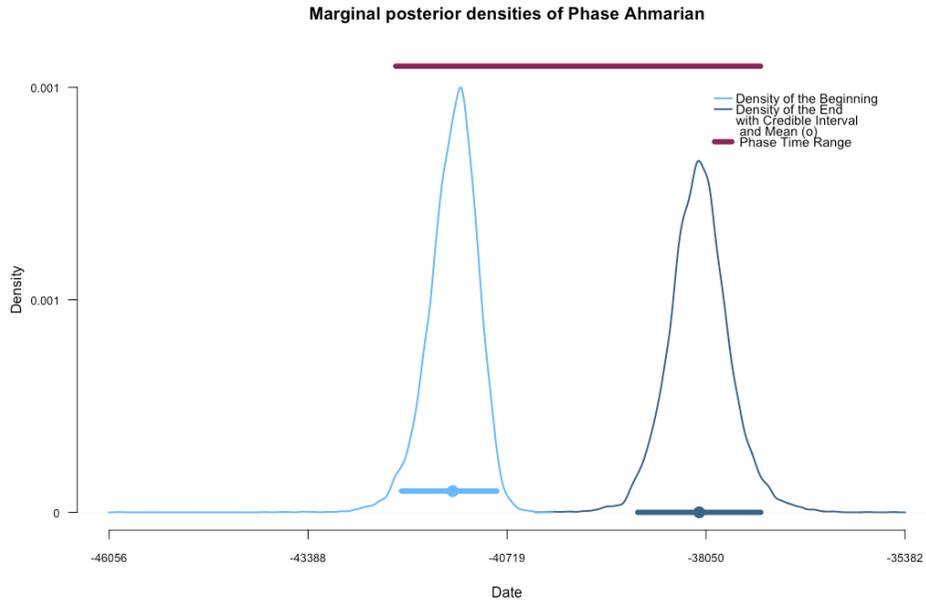


Figure 2: Plot of the marginal posterior densities of the beginning and the end of phase Ahmarian

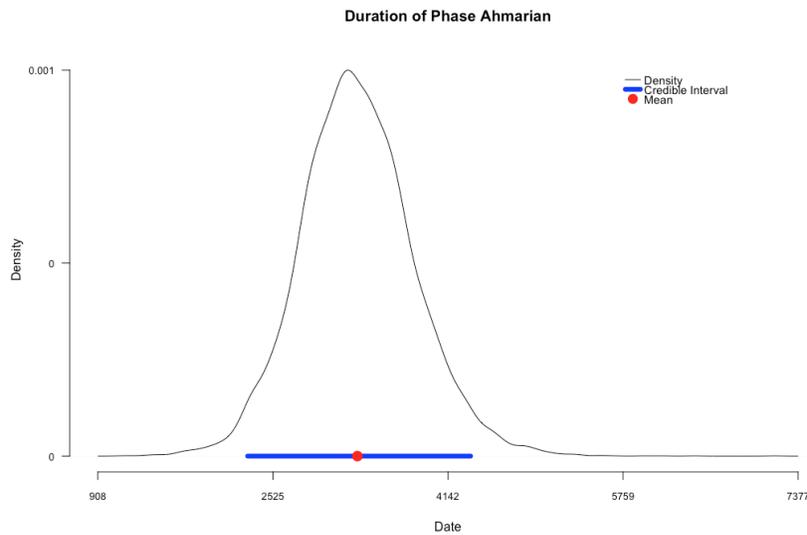


Figure 3: Plot of the marginal posterior densities related to phase Ahmarian

5.4 Examining the succession of two phases

Let's use for this example the succession of phases "Layer XVII" and "Layer XVI", that are a part of the stratigraphic succession. As these phases are in temporal order, we can estimate, if it exists, the gap (or hiatus) and the transition interval between both phases (See section 2 for more details).

To do that, let's use the following lines.

```
1 ## Gap interval between two successive phases
2 # confidence level = 0.95
3 PhasesGap(Layer.XVII.beta, Layer.XVI.alpha)
4 # confidence level = 0.20
5 PhasesGap(Layer.XVII.beta, Layer.XVI.alpha, level = 0.2)
6
7 # Transition interval between two successive phases
8 # confidence level = 0.95
9 PhasesTransition(Layer.XVII.beta, Layer.XVI.alpha)
```

programmesR/TransitionGapBetweenTwoSuccessivePhases.R

The output is

```
> PhasesGap(Layer.XVII.beta, Layer.XVI.alpha)
      level HiatusIntervalInf HiatusIntervalSup
      "0.95"                "NA"                "NA"
> PhasesGap(Layer.XVII.beta, Layer.XVI.alpha, level = 0.2)
      level HiatusIntervalInf HiatusIntervalSup
      0.2      -38956.0      -38906.0
> PhasesTransition(Layer.XVII.beta, Layer.XVI.alpha)
      0.95 TransitionRangeInf TransitionRangeSup
      0.95      -40299.00      -38043.00
```

Lines 3 and 5 ask for the endpoints of the gap interval between both phases. The default confidence level is 0.95. For this confidence level, no hiatus exists between "Layer XVII" and "Layer XVI". However, for a confidence level fixed at 0.20, there exists a gap of 50 years between both phases.

Line 9 asks for the transition interval given a 0.95 confidence level. At this level, the transition starts at -40 299 and ends at -38 043.

All these pieces of information may be illustrated on a graphic using the following command line:

```
1 SuccessionPlot(Layer.XVII.alpha, Layer.XVII.beta, Layer.XVI.alpha, Layer.XVI.beta)
```

programmesR/SuccessionPlot.R

Figure 4 presents the resulting graph. As the gap interval associated with the confidence level 0.95 does not exist, hence a point is drawn instead.

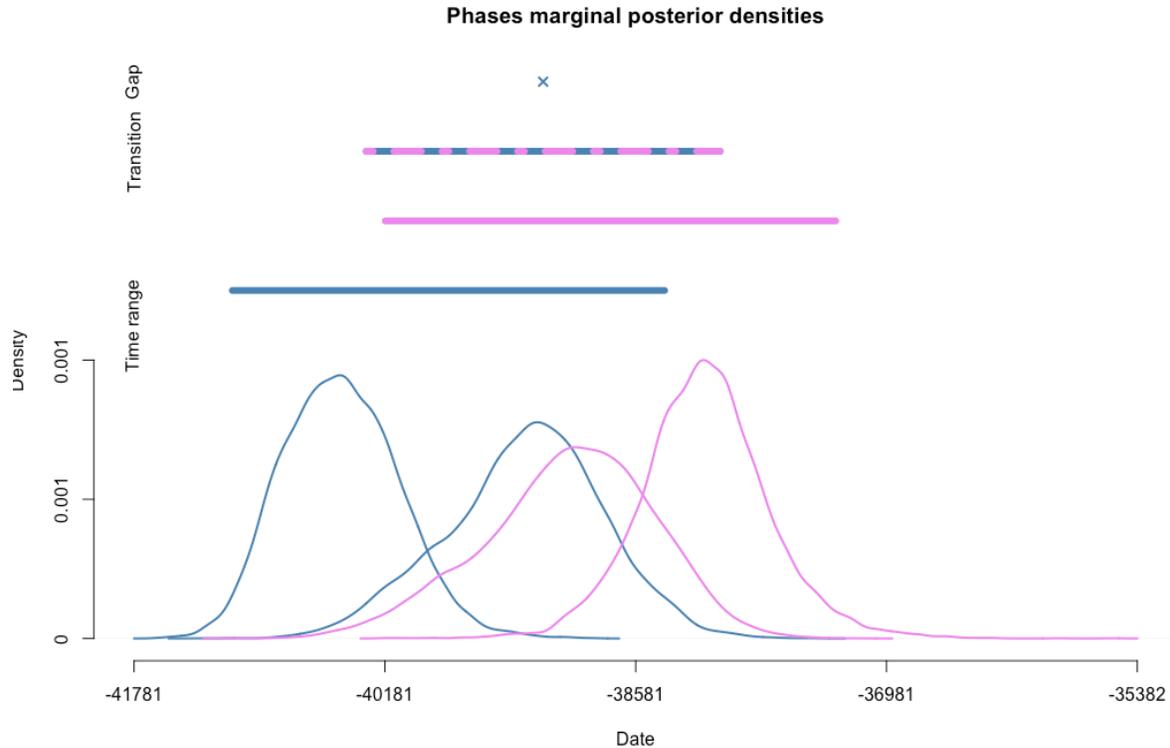


Figure 4: Plot of the succession of phases "Layer XVII" and "Layer XVI" and 95% intervals. Curves represent the densities of the beginning and end of phases. The oldest phase is drawn in blue, the youngest phase in violet. Segments correspond to time range of the phase of the same color, two-coloured segments correspond to transition interval or to the gap range. A cross instead of a two-coloured segment means that there is no gap range at the desired level of confidence.

5.5 Examining a series of phases

We may also be interested in a series of phases, as for instance the following phases of Ksar Akil: IUP, Ahmarian, UP and EPI. Let assume that we do not know about their temporal order succession. We could, for example, wish to know the time range of these different phases, or we could want to draw the different beginnings and ends on a same graph. We could also wish to know the credible interval of all beginnings.

To do that, the "Multi" functions are available. For data extracted from ChronoModel software, only the vector of positions of all phases' beginnings are needed. Otherwise, the vector of positions of the phases' ends is also required.

For our example, let's use the following lines.

```

1 # Phase time ranges
2 MultiPhaseTimeRange(Phases , c(2,4,6,14))
3

```

```

4 # Phase plots
5 MultiPhasePlot(Phases, c(2,4,6,14), title="Phases EPI, UP, Ahmarian et IUP")
6
7 # Credible intervals
8 MultiCredibleInterval(Phases, c(2,4,6,14))

```

programmesR/MultiFunctions.R

The result of line 2 is :

```

> # Phase time ranges
> MultiPhaseTimeRange(Phases, c(2,4,6,14))

```

		Level	TimeRangeInf	TimeRangeSup
EPI.alpha	EPI.beta	0.95	-28983	-26951
UP.alpha	UP.beta	0.95	-38501	-29284
Ahmarian.alpha	Ahmarian.beta	0.95	-42211	-37319
IUP.alpha	IUP.beta	0.95	-43272	-41155

```

>

```

Phase "EPI" whose beginning output is in column 2 has a time range = [-28 983, -26 951] at a confidence level = 0.95 and the phase "IUP" whose beginning output is in column 14 has a time range = [-43 272, -41 155].

Line 5 generates a plot presented in Figure 5 with the densities of the beginning and the end of these four phases and their time ranges. The marginal posterior densities of phase IUP are drawn in green, those of phase Ahmarian are in red, those of phase UP are in purple and those of phase EPI are in light blue. As there is only one event in the phases EPI and IUP, the beginning and the end of these phases have the same values at each iteration. Hence, we can only see one curve for each of these phases. Time range are displayed by segment of the same color as the densities of the phase.

Line 8 computes the credible interval for the beginning of each of these phases. The result is :

```

> # Credible intervals
> MultiCredibleInterval(Phases, c(2,4,6,14))

```

	Level	CredibleIntervalInf	CredibleIntervalSup
EPI.alpha	0.95	-28974.5	-26949.9
UP.alpha	0.95	-38519.7	-36685.7
Ahmarian.alpha	0.95	-42134.5	-40856.9
IUP.alpha	0.95	-43268.8	-41154.1

```

>

```

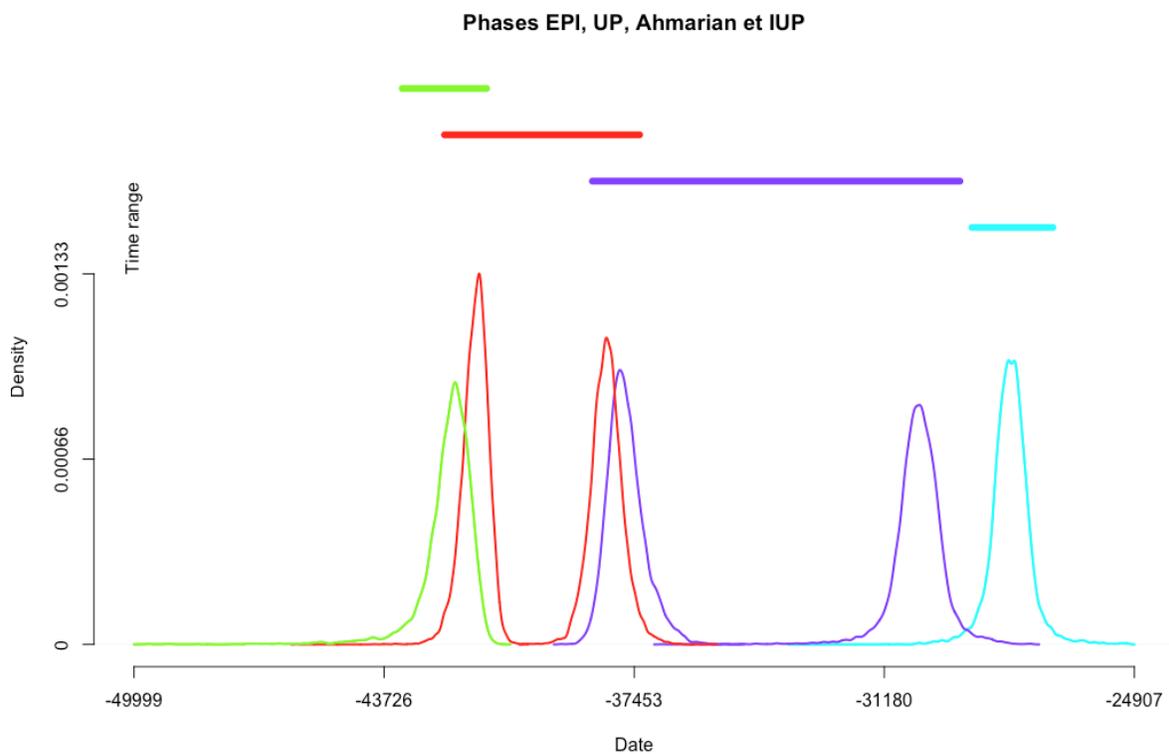


Figure 5: Plot of the series of phases and their associated time range at 95%. Curves represent the densities of the beginning and end of phases. Segments correspond to time range of the phase of the same color.

5.6 Examining a succession of phases in temporal order

We may also be interested in a succession of phases. This is actually the case of the succession of IUP, Ahmarian, UP and EPI that are in stratigraphic order. Hence, we can estimate the transition interval and, if it exists, the gap between these successive phases. This may be done using the following code :

```
1 # Phases Gap
2 MultiPhasesGap(Phases, position_beginning=c(14,6,4,2))
3
4 # Phases Transition
5 MultiPhasesTransition(Phases, position_beginning=c(14,6,4,2))
6
7 # Succession plot
8 MultiSuccessionPlot(Phases, position_beginning=c(14,6,4,2), title="Ksar Akil -
  Succession of phases : IUP, Ahmarian, UP, EPI ")
```

programmesR/MultiSuccession.R

For these functions, the order of the phases is important. The vector of positions of the beginning should start with the beginning of the oldest phase and end with the one of the youngest phase. For data extracted from ChronoModel, the vector of positions of the phases' ends is deduced from the vector of the beginning. For other data, this vector should be specified.

The results of lines 2 and 5 are the following

```
> MultiPhasesGap(Phases, c(14,6,4,2))
              Level HiatusIntervalInf HiatusIntervalSup
IUP.beta & Ahmarian.alpha "0.95" "NA"                "NA"
Ahmarian.beta & UP.alpha  "0.95" "NA"                "NA"
UP.beta & EPI.alpha      "0.95" "-29202"            "-29110"
>
> # Phases Transition
> MultiPhasesTransition(Phases, c(14,6,4,2))
              0.95 TransitionRangeInf TransitionRangeSup
IUP.beta & Ahmarian.alpha 0.95          -43272          -40704
Ahmarian.beta & UP.alpha  0.95          -39042          -36686
UP.beta & EPI.alpha       0.95          -31553          -26965
>
```

Figure 6 presents the resulting plot of line 8. In that case, the marginal posterior densities of phase IUP are drawn in green, those of phase Ahmarian are in purple, those of phase UP are in light blue and those of phase EPI are in red. Again, as there is only one event in the phases EPI and IUP, the beginning and the end of these phases have the same values at each iteration. Hence, we can only see one curve for each of these phases. Time range are displayed by segment of the same color as the densities of the phase. As there are no gaps at 95% between phases IUP and Ahmarian, and Ahmarian and UP, a cross is drawn instead.

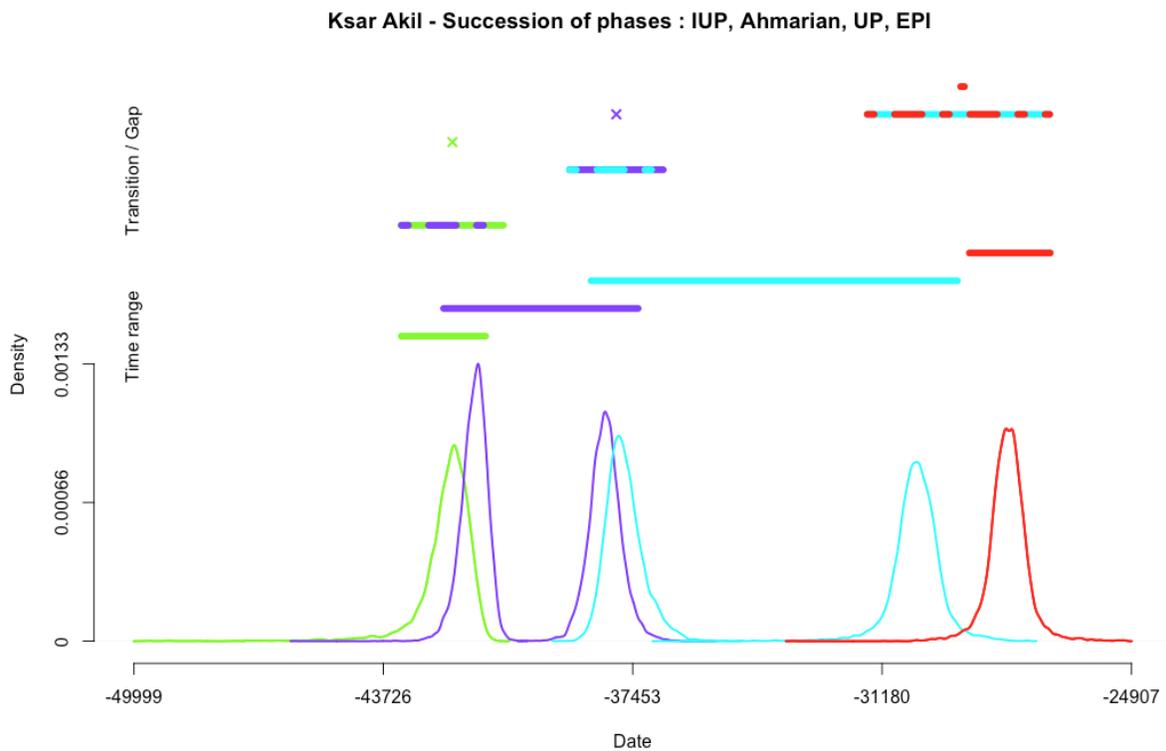


Figure 6: Plot of the succession of phases from Ksar Akil and intervals at 95%. Curves represent the densities of the beginning and end of each phase. Segments correspond to time range of the phase of the same color, two-coloured segments correspond to transition interval or to the gap range. A cross instead of a two-coloured segment means that there is no gap range at the desired level of confidence.

5.7 Conclusion

From data published by Bosch et al. [2] and the modelling done with ChronoModel and detailed in section 3, we can say that the succession of phases of Ksar Akil are as follow :

Phase	Time range		Transition range		Gap range (if it exists)	
IUP	-43 272	-41 155	NA	NA	NA	NA
Ahmarian	-42 211	-37 319	-43 272	-40704	NA	NA
UP	-38 501	-29 284	-39 042	-36 686	NA	NA
EPI	-28 983	-26 951	-31 553	-26 965	-29 202	-29 110

Figure 7: Results associated with a level of confidence at 95%

6 The ArchaeoPhases app

For people who do not know how to use R, there is a web application that allows you to take the advantages of all those functions without having to know R. It is available on <https://archaeology-bayesian-modelling.shinyapps.io/ArchaeoPhases>

Analysis of archaeological phases
Post-Processing of the Markov Chain Simulated by ChronoModel or by Oxcal

Home Import CSV Events Phases Several phases Succession of phases

This is a Shiny application for ChronoModel or Oxcal users who want to use RChronoModel package without having to know R software.
The process is very simple !
First model your chronology with ChronoModel or Oxcal or any other software for constructing archaeological chronologies.
Then extract the simulated Markov Chains and save it into a CSV file.
And finally, import this CSV file using the app and analyse your chronological phases.

To visite ChronoModel website
[Click Here!](#)

To visite Oxcal website
[Click Here!](#)

Ready to take the RChronoModel tutorial? If so
[Click Here!](#)

This application was developed by Anne Philippe and Marie-Anne Vibet
Maintainer : Anne Philippe <anne.philippe@univ-nantes.fr>

Figure 8: The ArchaeoPhases App

References

- [1] Bayesian Analysis of Radiocarbon Dates. *Radiocarbon*, 51(1):337–360, 2009.
- [2] Marjolein D. Bosch, Marcello A. Mannino, Amy L. Prendergast, Tamsin C. O’Connell, Beatrice Demarchi, Sheila M. Taylor, Laura Niven, Johannes van der Plicht, and Jean-Jacques Hublin. New chronology for Ksâr ‘Akil (Lebanon) supports Levantine route of modern human dispersal into Europe. *Proceedings of the National Academy of Sciences*, 112(25):7683–7688, jun 2015.
- [3] Ph. Lanos, A. Philippe, H. Lanos, and Ph. Dufresne. *Chronomodel : Chronological Modelling of Archaeological Data using Bayesian Statistics (Version 1.5).*, 2016.
- [4] C. Bronk Ramsey. *Oxcal 4.2*, 2016.
- [5] M-A Vibet, A. Philippe, Ph. Lanos, and Ph Dufresne. *ChronoModel V1.5 User’s manual*, 2016.