

Considering time

Goals

- methods of temporal analysis
 - calibration of radiocarbon data
 - working with temporal uncertainties - introduction to the aoristic method
- R
 - joining 2 tables
 - creating a new variable based on condition in different variable
 - some tips and tricks for your ggplot

Radiocarbon dating

Evocation

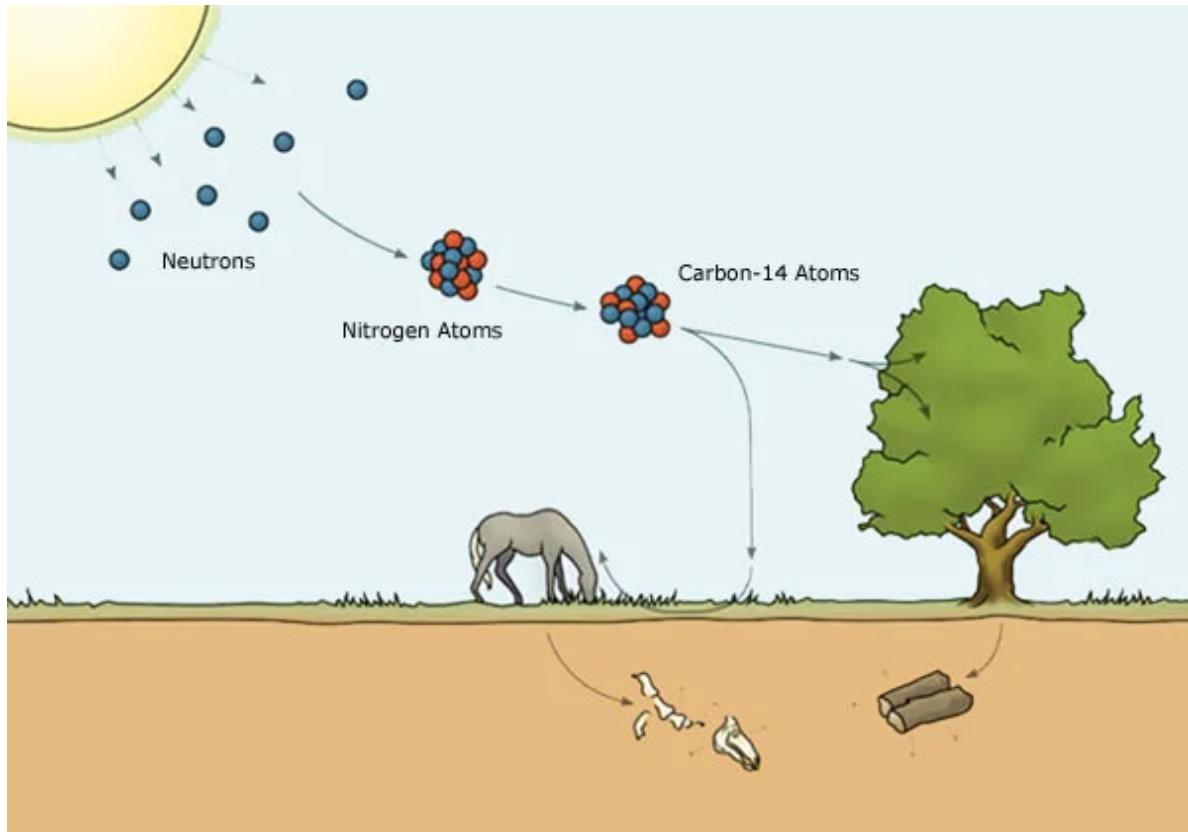
- What's the difference between *absolute* dating and *relative* dating?
- How the archaeologists estimated absolute dates before invention of the radiocarbon dating?
- Can you tell other methods of absolute dating?

How RC dating works

A very simple introduction

- It is based on measurement of proportion of radioactive ^{14}C in organic material.
- Plants are absorbing ^{14}C from atmosphere which then continues to animals and humans through food chain.
- After the death of the organism the ^{14}C starts to decay, and by measuring proportion of the ^{14}C still in the body and comparing it with the amount of ^{14}C in atmosphere, we can measure **time when the organism died**.

- Since the amount of the ^{14}C in atmosphere varies during time, we need to calibrate the results with so called “calibration curve”.
- Keep in mind that we are not dating a date of creation of the archaeological context, but date of the death of the organism, be it human individual, grain, or a tree.



For more information, see:

- Bayliss, A., and Marshall, P. 2022 [Radiocarbon Dating and Chronological Modelling: Guidelines and Best Practice](#)
- Renfrew, C., & Bahn, P.G. 1998. [Archaeology: theories, methods and practice](#)

Today's dataset

LASOLES

Let's try to calibrate some radiocarbon data!

We will do so with the same data as last time, from the LASOLES radiocarbon database of the Czech Republic.

```
library(dplyr)
library(ggplot2)

df_lasoles <- read.csv("./data/LASOLES_14C_database.csv", sep = ";")

df_lasoles$Age14C <- as.numeric(df_lasoles$Age14C)
df_lasoles$SD14C <- as.numeric(df_lasoles$SD14C)

head(df_lasoles[, 1:7], 12)
```

	ID	Date	Lab_code	Laboratory	Age14C	SD14C	Date_type	Delta_13C	
1	CzArch_1	Poz-41673		Poz	3345	30	conv.	14C BP	
2	CzArch_5		A-215		A	3040	45	conv.	14C BP
3	CzArch_6		Bln-102		Bln	6285	100	conv.	14C BP
4	CzArch_7		Bln-102a		Bln	6405	100	conv.	14C BP
5	CzArch_11		Bln-1165		Bln	4670	80	conv.	14C BP
6	CzArch_12		Bln-1166		Bln	4670	80	conv.	14C BP
7	CzArch_13		Bln-1167		Bln	2525	80	conv.	14C BP
8	CzArch_14		Bln-1167-A		Bln	2440	80	conv.	14C BP
9	CzArch_15		Bln-118		Bln	665	100	conv.	14C BP
10	CzArch_16		Bln-1244		Bln	4955	80	conv.	14C BP
11	CzArch_17		Bln-1396		Bln	4770	60	conv.	14C BP
12	CzArch_18		Bln-1396-A		Bln	4775	60	conv.	14C BP

Quick calibration

- We will use a real radiocarbon date sampled from a Final Eneolithic – Early Bronze Age site Pavlov u Dolních Věstonic, “Horní pole”.
- We will use package `rcarbon` and calibration curve [IntCal20](#)

Details

- uncalibrated date: **3990**
- standard deviation: **54**

Additional information

- laboratory code: Erl-4719
- typochronological datation: Bell Beaker Culture
- archaeological context: grave
- sample: human bone

Quick calibration

```
# install.packages("rccarbon")
library(rccarbon)
cal_date <- calibrate(x = 3990, errors = 54, calCurves = "intcal20")

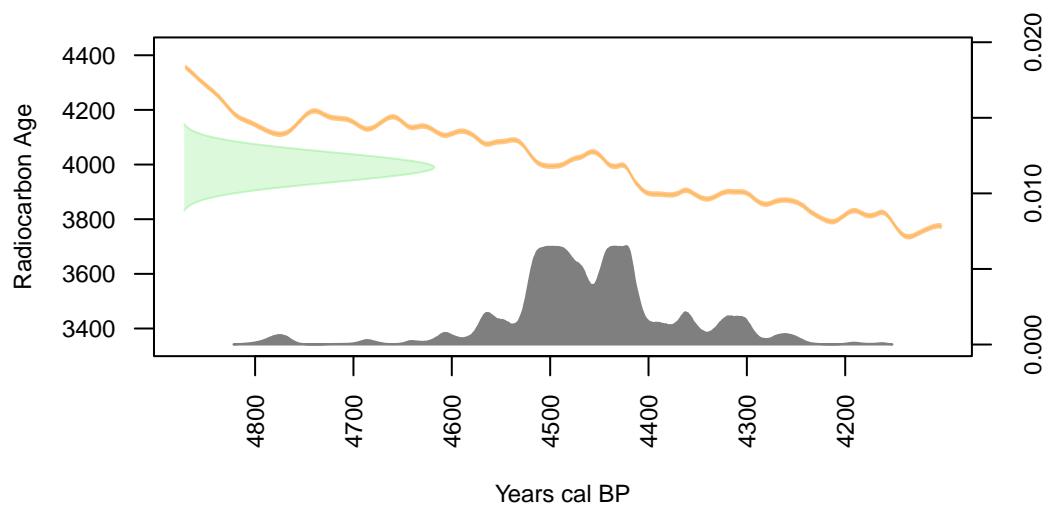
summary(cal_date)
```

	DateID	MedianBP	OneSigma_BP_1	OneSigma_BP_2	OneSigma_BP_3	TwoSigma_BP_1	
1	1	4464	4565 to 4562	4528 to 4406	4364 to 4360	4783 to 4768	
			TwoSigma_BP_2	TwoSigma_BP_3	TwoSigma_BP_4		
1	4614 to 4596	4583 to 4288	4272 to 4250				

Median of the calibrated date is **4464 BP**

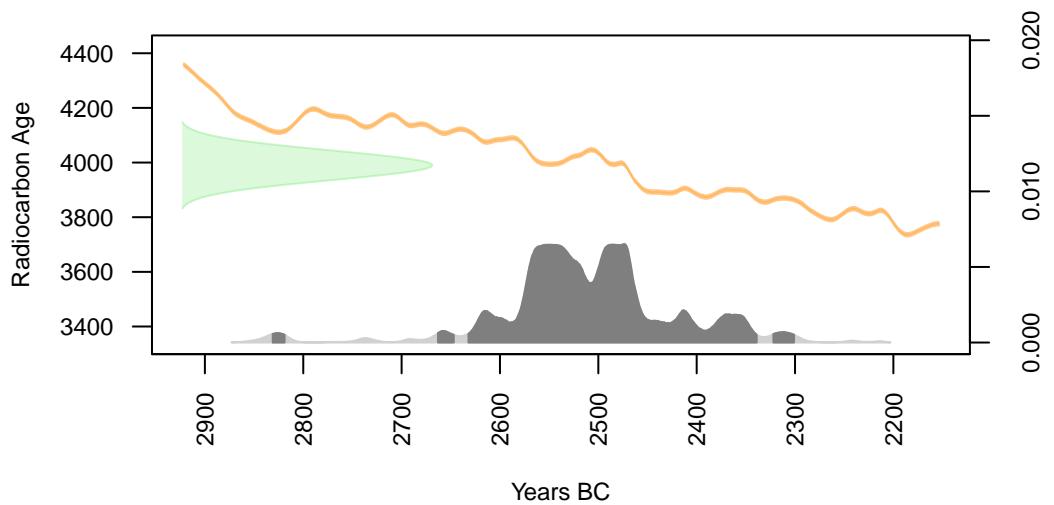
Quick plot

```
plot(cal_date)
```



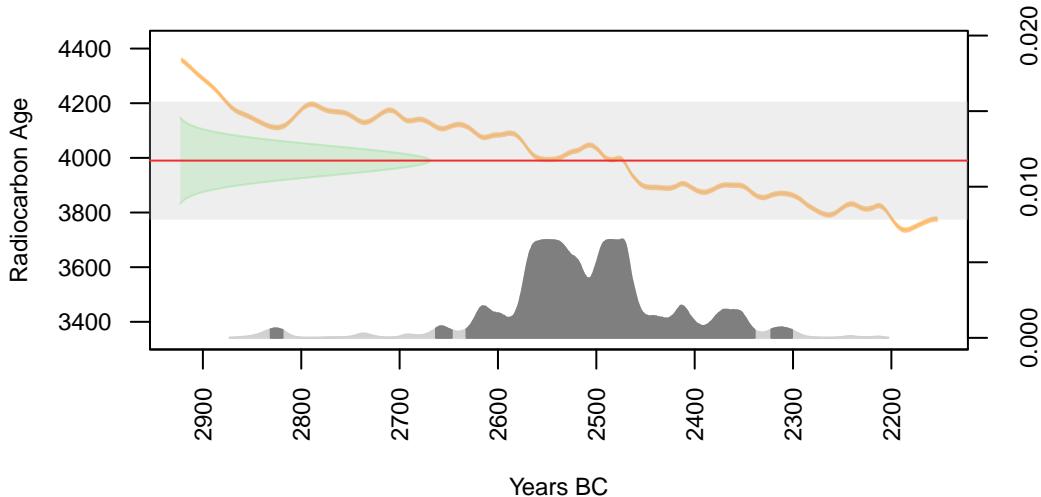
Improving your plot

```
plot(cal_date, calendar = "BCAD", HPD = TRUE)
```



- argument `HPD` highlights confidence of the posterior density, by default set to 95% (2 standard deviations)

Why I can't get single BCE number?



Plotting multiple samples

- let's create a subset with samples from our site, dated to the Final Eneolithic and Early Bronze Age and having no dating errors
- copy and paste this code from our web:

```
df_sample_site <- df_lasoles %>%
  filter(Civil_parish == "Pavlov u Dolních Věstonic" &
         Site_name == "Horní pole" &
         Age14C > 3500 &
         Age14C < 5000 &
         Dating_error == "n")
```

```
cal_dates <- calibrate(x = df_sample_site$Age14C, errors = df_sample_site$SD14C, calCurves =
```

```
head(summary(cal_dates), 4)
```

DateID	MedianBP	OneSigma_BP_1	OneSigma_BP_2	OneSigma_BP_3	OneSigma_BP_4
1 Erl-4709	4240	4383 to 4374	4352 to 4329	4297 to 4150	NA to NA

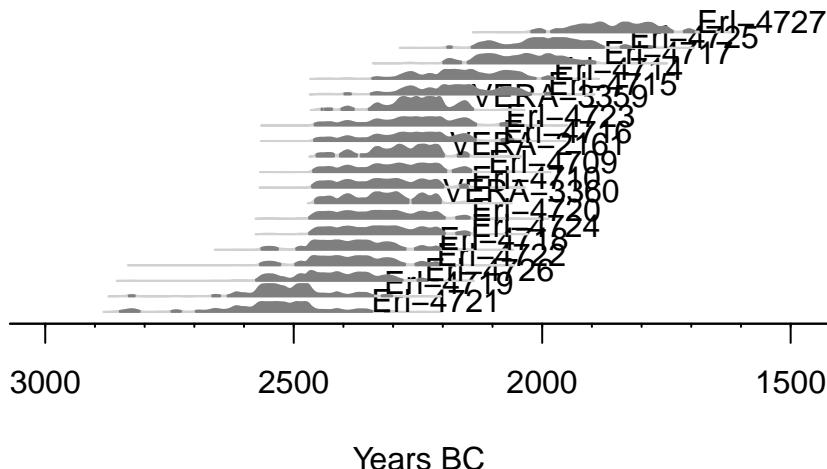
```

2 Erl-4710      4267  4398 to 4372  4353 to 4328  4299 to 4225  4204 to 4155
3 Erl-4714      4107  4228 to 4202  4156 to 4067  4046 to 3987      NA to NA
4 Erl-4715      4125  4232 to 4199  4183 to 4167  4159 to 4080  4037 to 3994
  OneSigma_BP_5 TwoSigma_BP_1 TwoSigma_BP_2 TwoSigma_BP_3 TwoSigma_BP_4
1      NA to NA  4411 to 4141  4130 to 4091      NA to NA      NA to NA
2      NA to NA  4412 to 4148  4116 to 4098      NA to NA      NA to NA
3      NA to NA  4343 to 4338  4292 to 3960  3950 to 3924      NA to NA
4      NA to NA  4349 to 4332  4295 to 3970  3944 to 3930      NA to NA

```

Multiplot

```
multiplot(cal_dates, decreasing=TRUE, HPD=TRUE, label.pos=0.9, label.offset=-200, calendar =
```



Radiocarbon dates as proxies for human demography

- in recent years, radiocarbon data are being widely used for determining relative demography
- different methods, e.g. summed probability distribution (SPD) or kernel density estimation (KDE)

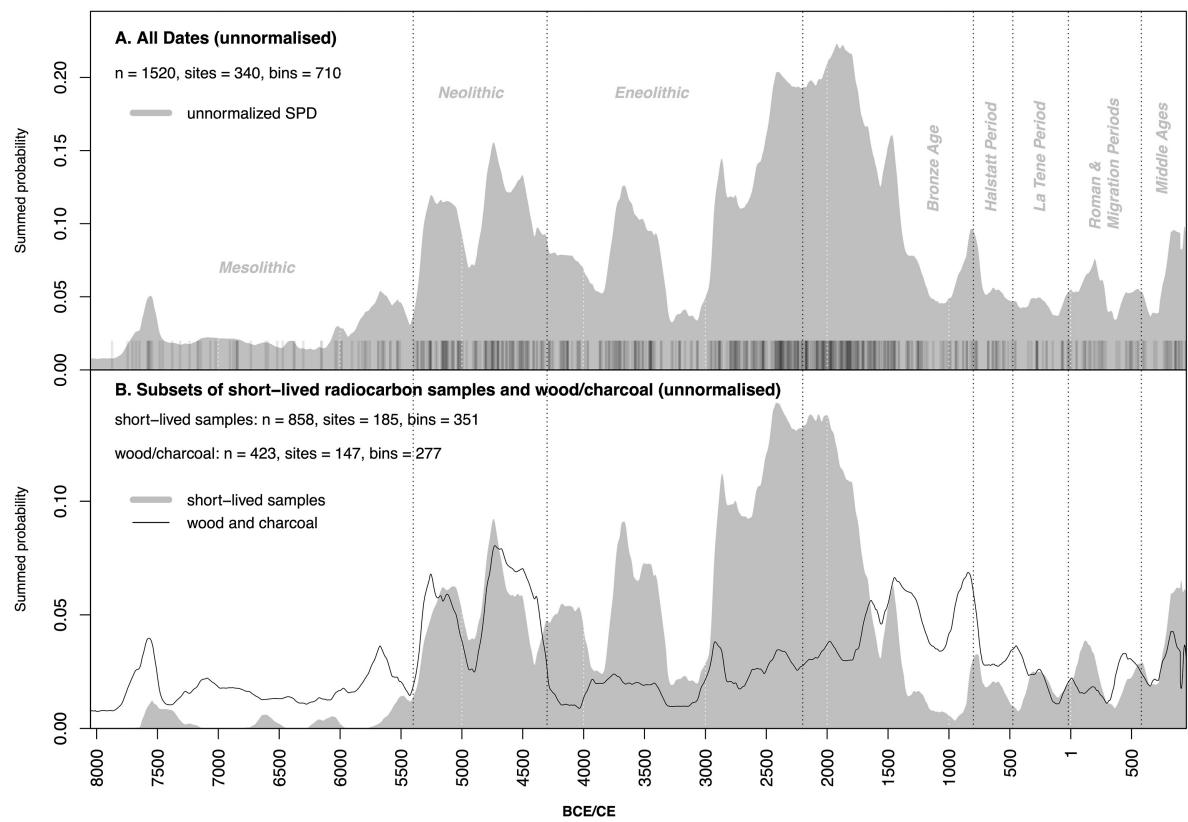


Figure 1: SPD, From Kolář, J., Macek, M., Tkáč, P., Novák, D., & Abraham, V. 2022. Long-term demographic trends and spatio-temporal distribution of past human activity in Central Europe: Comparison of archaeological and palaeoecological proxies. Quaternary Science Reviews 297: p.107834

RC Dates as proxies for demography

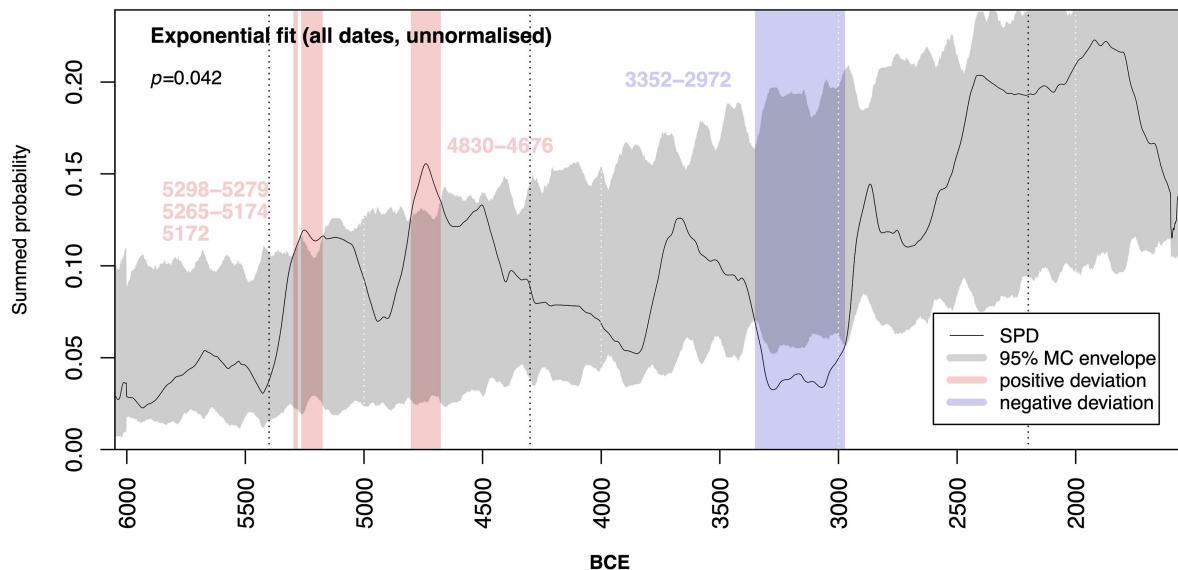


Figure 2: SPD - model, From Kolář, J., Macek, M., Tkáč, P., Novák, D., & Abraham, V. 2022. Long-term demographic trends and spatio-temporal distribution of past human activity in Central Europe: Comparison of archaeological and palaeoecological proxies. Quaternary Science Reviews 297: p.107834.

Where to find more info

This [article](#) provides step-by-step instruction for plenty other analyses, e.g. SPD

Analysing radiocarbon dates using the rcarbon package

Enrico Crema, Andrew Bevan

2023-08-24

- Introduction
- Installing and loading the *rcarbon* package
- Calibrating ^{14}C Dates
 - Normalisation
- Aggregating ^{14}C Dates: Summed Probability Distributions (SPD)
 - Binning
 - Visualising Bins
 - Thinning
 - Composite Kernel Density Estimates (CKDE)
- Hypothesis Testing
 - Testing against theoretical growth models
 - Testing against custom growth models
 - Testing Local Growth Rates
 - Point-to-Point Test
 - A Note on Model Fitting
 - Comparing empirical SPDs against each other
 - Spatial Analysis
 - Spatio-Temporal Kernel Density Estimates
 - Spatial Permutation Test
- References

Other packages for radiocarbon data

- [oxcAAR](#) - R interface for [Oxcal](#)
- [Behron](#) - for Bayesian modeling
- [c14](#) - package for “tidy” workflow with ^{14}C data (in experimental phase)
- [c14bazAAR](#) - archive of different open access radiocarbon databases
- [stratigraphr](#) - package for stratigraphy and chronology

Exercise

1. Clean your workspace, create a new script in your project folder, load the database [LASOLES](#).
2. Create a new dataframe with data from burial site *Vedrovice - Široká u lesa*, dated to *Linear Pottery Culture*.
3. Calibrate all the data and create a multiplot.

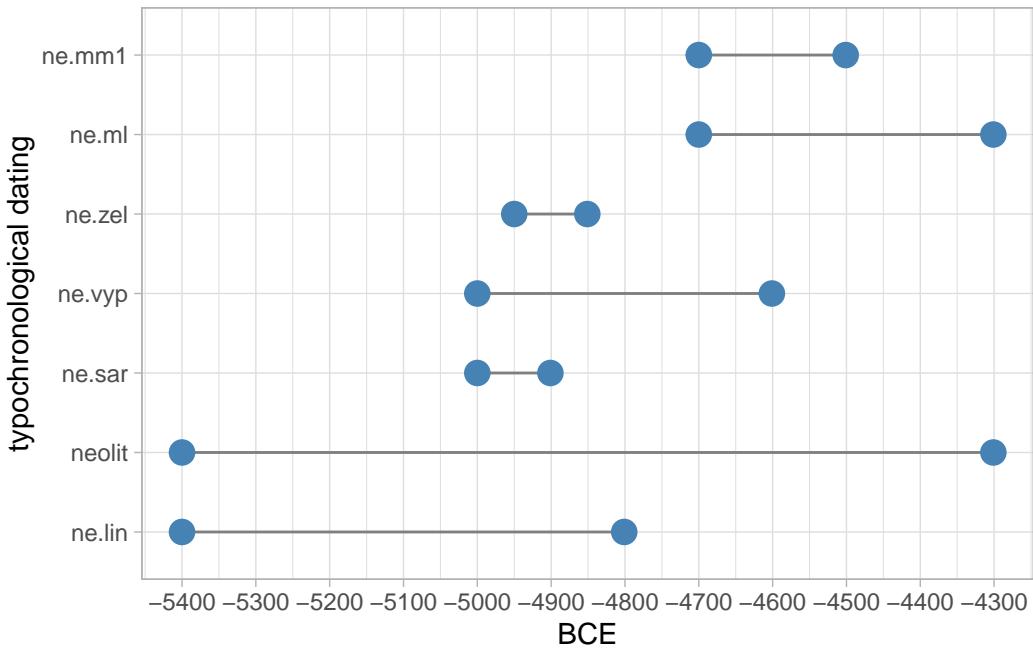
Hints: ne.lin, filter(), multiplot()

Working with temporal uncertainties

Problem

- Imagine you are trying to model intensity of human occupation in longer time period by quantifying archaeological contexts but you are struggling with the problem how to compare contexts with various accuracy of their dating.
- E.g. some contexts are dated vaguely to “neolithic period” because the only artefact found there was a culturally insignificant polished axe. And on the contrary, other contexts are dated to shorter periods such as “Stroked Pottery Culture period” (*vypíchaná ker.*) thanks to finds of recognizable ornamented pottery.





Aoristic method

- will help us with overcoming difficulties with temporal uncertainties
- see [Crema, E.R. 2012](#) for more details
- what we need:
 - for every archaeological context we need a typo-chronological datation and start date and end date of each of these datations, such as in example below:

	context_number	context_dating_AMCR	date_start	date_end
1	pit1	ne.lin	-5400	-4801
2	pit2	neolit	-5400	-4301
3	pit3	ne.lin	-5300	-4801
4	grave1	ne.lin	-5300	-4801

Joining two tables together

- for the sake of the simplicity and for these educational purposes, we will work with LASOLES database as if it does not consist of radiocarbon samples but of contexts of these samples dated typochronologically to various periods
- but since LASOLES does not have variables with information about start and end date, we will need to get those information from another dataset - `datation_mor.csv`

```
df_datations <- read.csv(here("datation_mor.csv"))
```

```
head(df_datations, 4)
```

	kultura	date_start	date_end
1	mezoli	-9600	-5401
2	ne.lin	-5400	-4801
3	ne-en	-5400	-2001
4	neolit	-5400	-4301

- now we need to add variables `date_start` and `date_end` to dataframe `df_lasoles`. We will do so by joining the two tables through variables “`kultura`” and “`Contex_dating_AMCR`” by command `right_join`

```
df_lasoles <- df_lasoles %>%
  right_join(df_datations, by = c("Contex_dating_AMCR" = "kultura"))
```

```
df_lasoles$date_start <- as.numeric(df_lasoles$date_start)
df_lasoles$date_end <- as.numeric(df_lasoles$date_end)
```

- see [documentation](#) for different types of joins

Saving your new dataframe

You can save your new dataframe now so you don't need to join the tables again next time:

```
write.csv(df_lasoles, file = here("df_lasoles2.csv"), row.names = FALSE)
```

Calculation of the aoristic sum

Package - `aoristaAAR`

```
if(!require('devtools')) install.packages('devtools')

library(devtools)
install_github('ISAAKiel/aoristAAR')

library(aoristAAR)
```

Calculation:

```
library(aoristAAR)

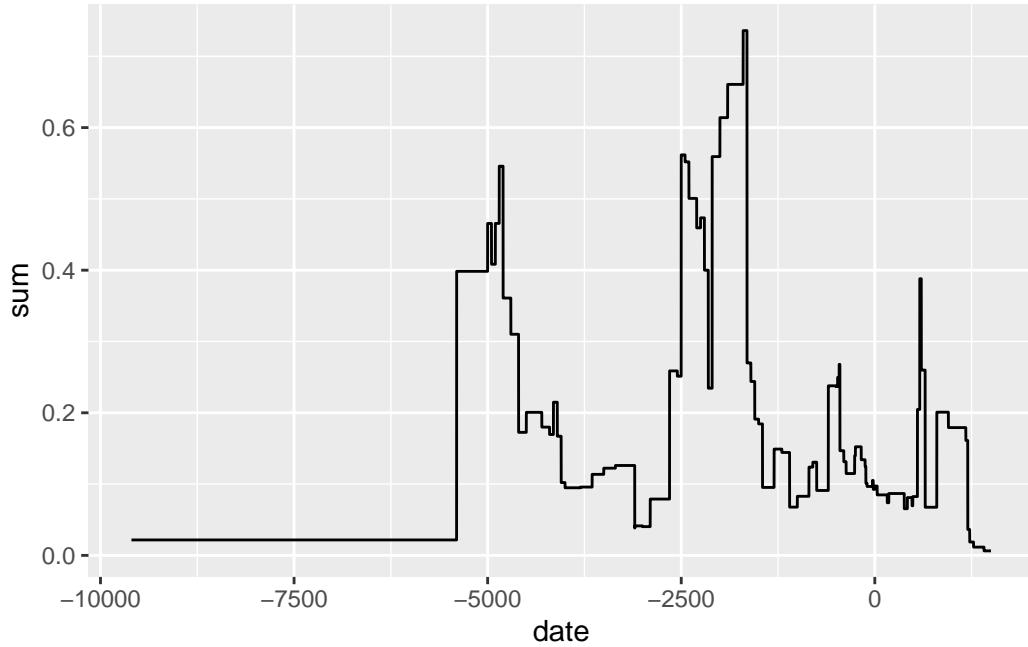
aori <- aorist(df_lasoles, from = "date_start", to = "date_end", method = "period_correction"
head(aori, 4)
```

```
# A tibble: 4 x 2
  date      sum
  <int>    <dbl>
1 -9600  0.0217
2 -9599  0.0217
3 -9598  0.0217
4 -9597  0.0217
```

Plot

Quick plot:

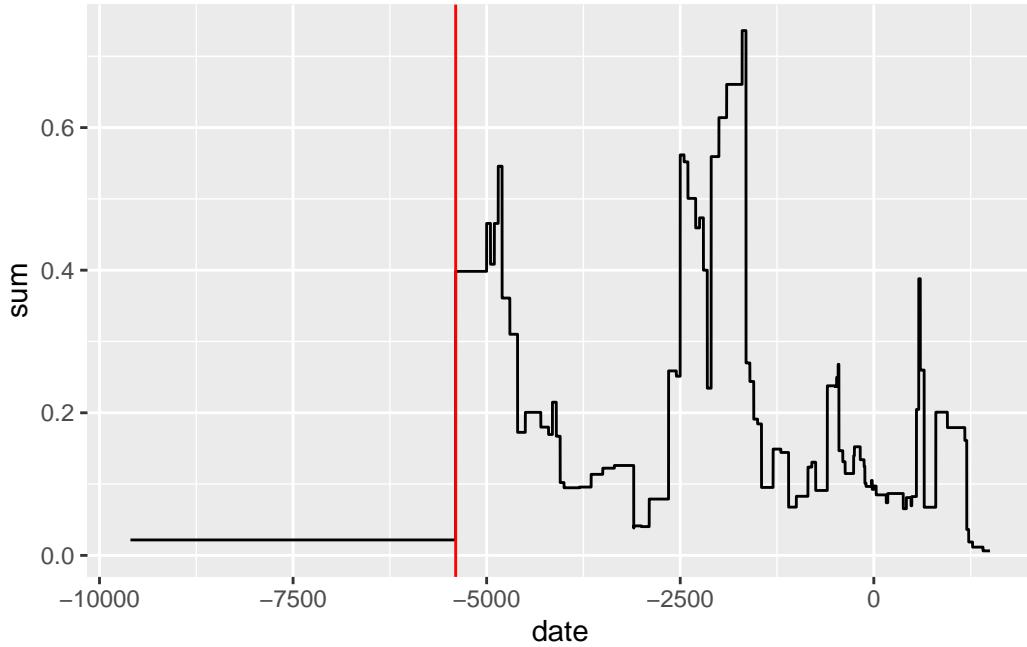
```
ggplot()+
  geom_line(data = aori, aes(x=date, y=sum))
```



Improving your plot

- command `geom_vline` adds vertical line on coordinates defined by you
- in this case, we mark -5400 BCE

```
ggplot()+
  geom_line(data = aori, aes(x=date, y=sum))+
  geom_vline(xintercept = -5400, color = "red")
```



But why stop here?

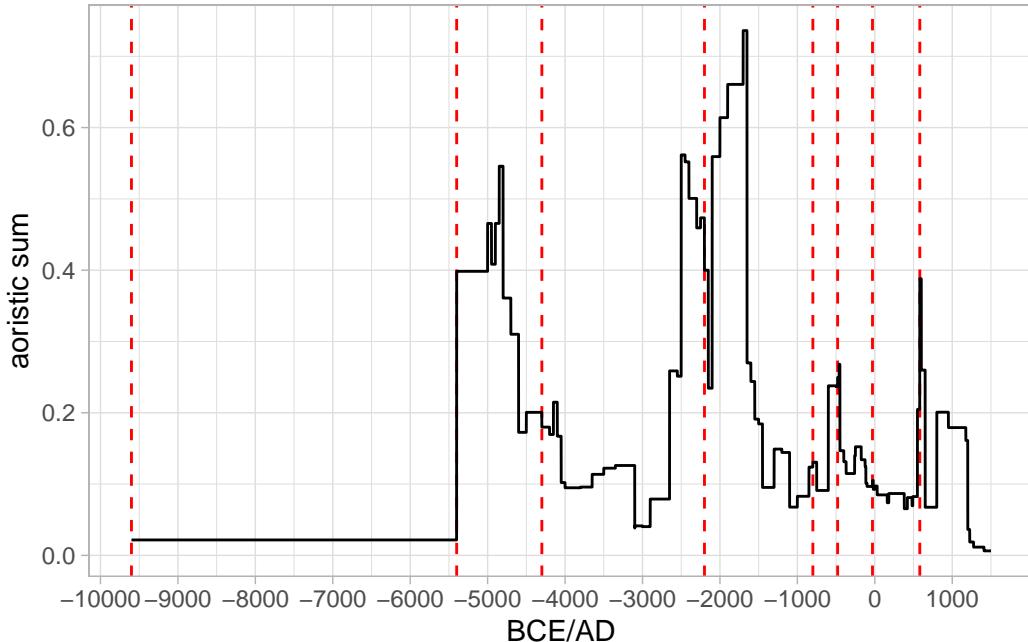
- lets mark the periods in your plot and divide the x-axis by 1000 years!

```

periods <- c(-9600, -5400, -4300, -2200, -800, -480, -30, 581)
marks <- seq(-10000, 1500, by = 1000)

ggplot()+
  geom_vline(xintercept = periods, color = "red", linetype = 2)+
  geom_line(data = aori, aes(x=date, y=sum))+
  scale_x_continuous(breaks = marks)+
  labs(x="BCE/AD", y="aoristic sum")+
  theme_light()

```



- notice that when we've changed the order of the lines so the later overlaps the earlier
- for the sake of simplicity, we will ignore the year "0" which should not exist

Grouping areas into broader categories

What if we want to observe differences in aoristic sum for different site category? For example settlements versus burial sites?

- first, we can check how many different site categories are being used

```
unique(df_lasoles$Site_category_ENG)
```

[1] "hillfort"	"settlement"
[3] "unpublished"	"large circular enclosure"
[5] "burial ground"	"settlement-exp"
[7] "cave or abri"	"extraction site"
[9] "ritual site"	"enclosure"
[11] "tumuli"	"hoard other"
[13] "secondary find"	"hoard of bronze artefacts"
[15] "single find"	"military camp"
[17] "hoard of ceramic vessels"	NA

There are too many areals for any usefull visualisation, so we need to group them to broader categories. For example burial grounds and tumuli will be in one category only.

- first step is creating vectors of site categories:

```
l_settlements <- c("settlement", "hillfort", "settlement-exp", "military camp", "large circuit", "large enclosure")
l_burials <- c("burial ground", "tumuli")
l_hoards <- c("hoard of a bronze artefacts", "hoard other", "hoard of ceramic vessels")
l_other <- c("single find", "cave or abri", "secondary find", "extraction site", "unpublished")
```

- then with the help of `mutate` will create a new variable “new_category”

```
df_lasoles <- df_lasoles %>%
  mutate(new_category = ifelse(Site_category_ENG %in% l_settlements, "settlements",
                               ifelse(Site_category_ENG %in% l_burials, "burials",
                                      ifelse(Site_category_ENG %in% l_hoards, "hoards",
                                             ifelse(Site_category_ENG %in% l_other, "other",
                                                   "no-data")))))
```

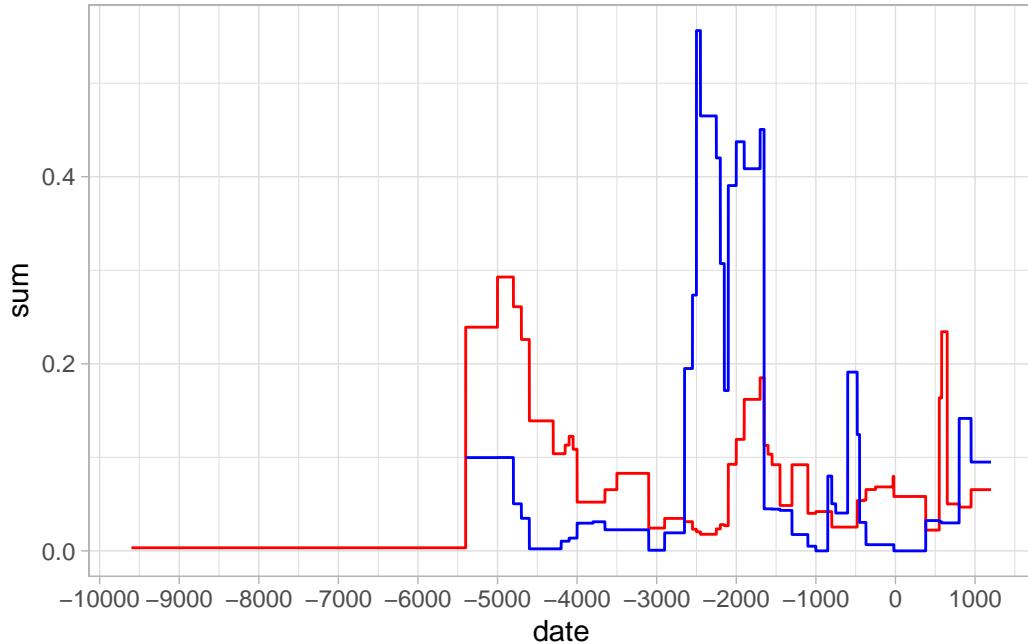
Aoristic for different categories

Now we can create aoristic sum for each new site category. Let's try it for settlements and burials:

```
df_settlements <- df_lasoles %>%
  filter(new_category == "settlements")
df_burials <- df_lasoles %>%
  filter(new_category == "burials")

aori_settlements <- aorist(df_settlements, from = "date_start", to = "date_end", method = "period")
aori_burials <- aorist(df_burials, from = "date_start", to = "date_end", method = "period")

ggplot()+
  geom_line(data = aori_settlements, aes(x=date, y=sum), color = "red")+
  geom_line(data = aori_burials, aes(x=date, y=sum), color = "blue")+
  scale_x_continuous(breaks = marks)+
  theme_light()
```



Easy subsetting

- you can create similar subsets without creating a new variable:

```

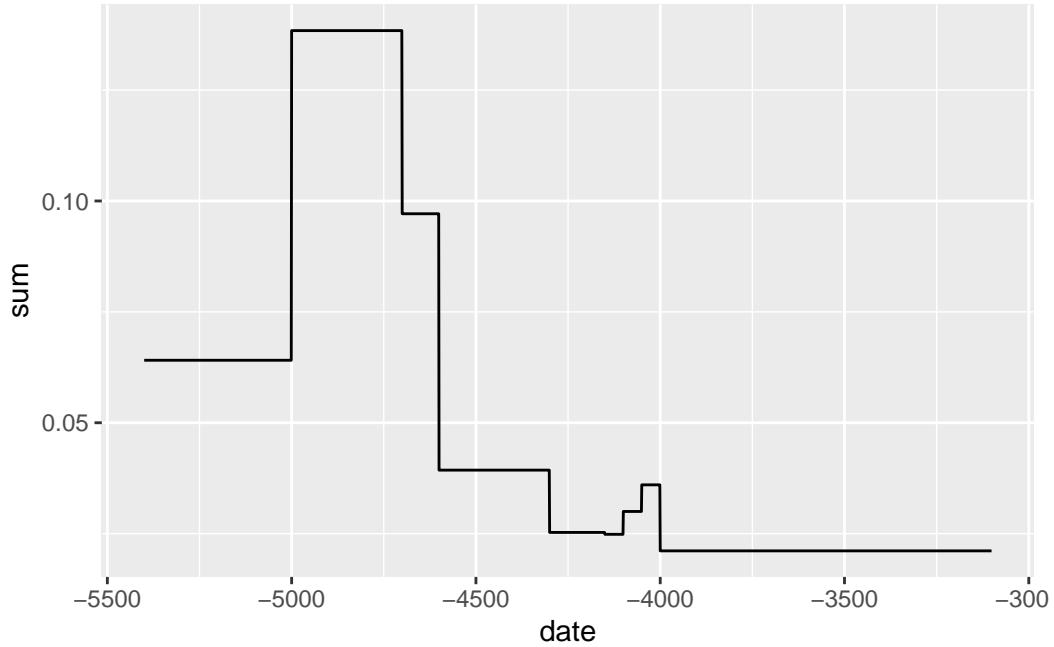
l_enclosures <- c("large circular enclosure", "enclosure")

df_enclosures <- df_lasoles %>%
  filter(Site_category_ENG %in% l_enclosures)

aori_encl <- aorist(df_enclosures, from = "date_start", to = "date_end", method = "period_collapse")

ggplot() +
  geom_line(data = aori_encl, aes(x=date, y=sum))

```



Exercise

1. clean your workspace, create new script, load either the new lasoles table (with end and start dates) or the old one, but then join it with datation table
2. create a dataframe of fortificated areas, consisting of hillforts, elevated settlements (settlement-exp) and military camps
3. calculate an aoristic sum for these fortificated areas and show it in ggplot
4. add marks to your ggplot visualizing the start and the end of the Iron age period (-800 and -21 BCE)
5. create a map of those fortified areas in the Czech republic (you will need to create a `sf` file and load “republika” from `RCzechia`)
6. create the same map, but only in Olomoucký kraj