This paper is a non-peer reviewed preprint submitted to EarthArXiv.

serac: a R package for ShortlivEd RAdionuclide Chronology of recent sediment cores

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1. Abstract

Short-lived radionuclides are measured in surface sediment to provide a geochronology for the past century. Age-depth models can be produced from $^{210}Pb_{ex}$ activity-derived sedimentation rates and confirmed by ^{137}Cs and ^{241}Am activities that are result of fallout from nuclear weapon tests and the Chernobyl accident. Different methods of age depth modelling using such data require expertise in lake sedimentation processes.

Here, we present a package, *serac*, that allows the user to compute an age-depth model, output a graph and an age model as a text file, and provide metadata using the free open-source statistical software R. *serac* ensures the reproducibility of age-depth or age-mass depth models and allows testing of several $^{210}Pbex$ models (CFCS, CIC, CRS) and sedimentation hypotheses (changes in the sedimentation rates, instantaneous deposits, varved sedimentation, etc.). Using several case studies, including lakes and lagoon in different environments, we demonstrate the use of the programme in diverse situations that may be encountered.

The rising number of sediment cores in recent palaeo studies and the need to correlate them require reproducible methods. *serac* is a user-friendly code that enables age model computation for the past century and encourages the standardisation of outputs.

Keywords: Shortlived radionuclide; R package; ^{210}Pb model; ^{137}Cs; age model; metadata

2. Introduction

Dating sediments is the first and critical step of any palaeo-study. If annual varves are absent, short-lived radionuclides provide the most accurate and widely used age-depth model technique for the past century. Accurately dating this period is crucial in palaeoclimate and palaeoecological studies because it contains many socio-ecological changes. Furthermore, there is a great amount of instrumental and historical data (e.g., floods, constructions) for this period, and a precise age-model is needed to correlate these data to proxies. Short-lived radionuclide dating is based on measurements of the activity of ^{137}Cs, ^{241}Am, ^{210}Pb, and ^{226}Ra. ^{137}Cs and ^{241}Am can provide up to three anchoring points to constrain age-depth models from 1950 AD on. However, they only contribute to linear models, assuming that the sedimentation remained constant; however, in natural environmental contexts, sedimentation is affected by different processes (floods, river channel changes) and/or human activities (dam construction, eutrophication, agriculture). However, ^{210}Pb and ^{226}Ra activities can be used to reconstruct the rate of decay of the excess ^{210}Pb and to infer sedimentation rates and ages.

Over the decade following 1955, nuclear weapons tests by the United-States, the former URSS, and the United Kingdom released nuclear by-products into the atmosphere. The isotope ^{137}Cs ($t_{1/2}$= 30.15 years) peaked in 1963, accompanied by a smaller peak in ^{241}Am ($t_{1/2}$= 432 years), which results from ^{241}Pu decay (one of the elements in fallout from atmospheric nuclear weapons tests). The Chernobyl accident in 1986 further dispersed ^{137}Cs into the atmosphere of the northern hemisphere (Appleby et al., 1991). Independent of human activities, ^{210}Pb excess activity can be used to estimate environmental sedimentation dynamics. ^{210}Pb is an isotope of lead that forms during the decay sequence of ^{238}U. The basic methodology of ^{210}Pb dating was first established in a seminal paper by Goldberg (1963). ^{210}Pb comes results from the disintegration of ^{226}Ra in rock, sediments and water, and from the disintegration of ^{222}Rn in the atmosphere (Figure 1). While ^{226}Ra and ^{210}Pb triggered by erosion in the watershed are in secular equilibrium (^{210}Pb supported), the ^{210}Pb produced in the atmosphere by ^{222}Rn decay are removed from the atmosphere by dry and wet fallout and are integrated in soils, lakes and sediments (Figure 1, excess ^{210}Pb, referred to hereafter as $^{210}Pb_{ex}$). As a consequence, it is possible to estimate the atmospheric $^{210}Pb_{ex}$ by subtracting the total ^{210}Pb by ^{226}Ra. The $^{210}Pb_{ex}$ activity follows an exponential decay (characterised by its half-life $t_{1/2}$= 22.3 years) from which it is possible to calculate the sedimentation rate for the past 100 to 150 years (~5 x $t_{1/2}$). Several models to infer ages from $^{210}Pb_{ex}$ decay have been recently proposed (Appleby, 2008, 2001; Appleby and Oldfield, 1992; Arias-Ortiz et al., 2018; Sanchez-Cabeza and Ruiz-Fernández, 2012) and several limitations have been described (Baskaran et al., 2014; Binford, 1990; Cooke et al., 2010; Kirchner, 2011). These isotopes are also used in chronologies from corals (Andrews et al., 2009; Druffel et al., 1990; Moore and Krishnaswami, 1972; Sabatier et al., 2012) and speleothems (Baskaran and Iliffe, 1993; Condomines and Rihs, 2006) through excess or ingrowth methods. ^{210}Pb can be detected by alpha-spectrometry determination of its daughter ^{210}Po ($t_{1/2}$= 138 d); however, ^{137}Cs, ^{241}Am, ^{210}Pb, and ^{226}Ra are mostly measured together in a non-destructive gamma-spectrometric analysis. This second method allows a direct determination of ^{210}Pb supported through the ^{226}Ra activity.

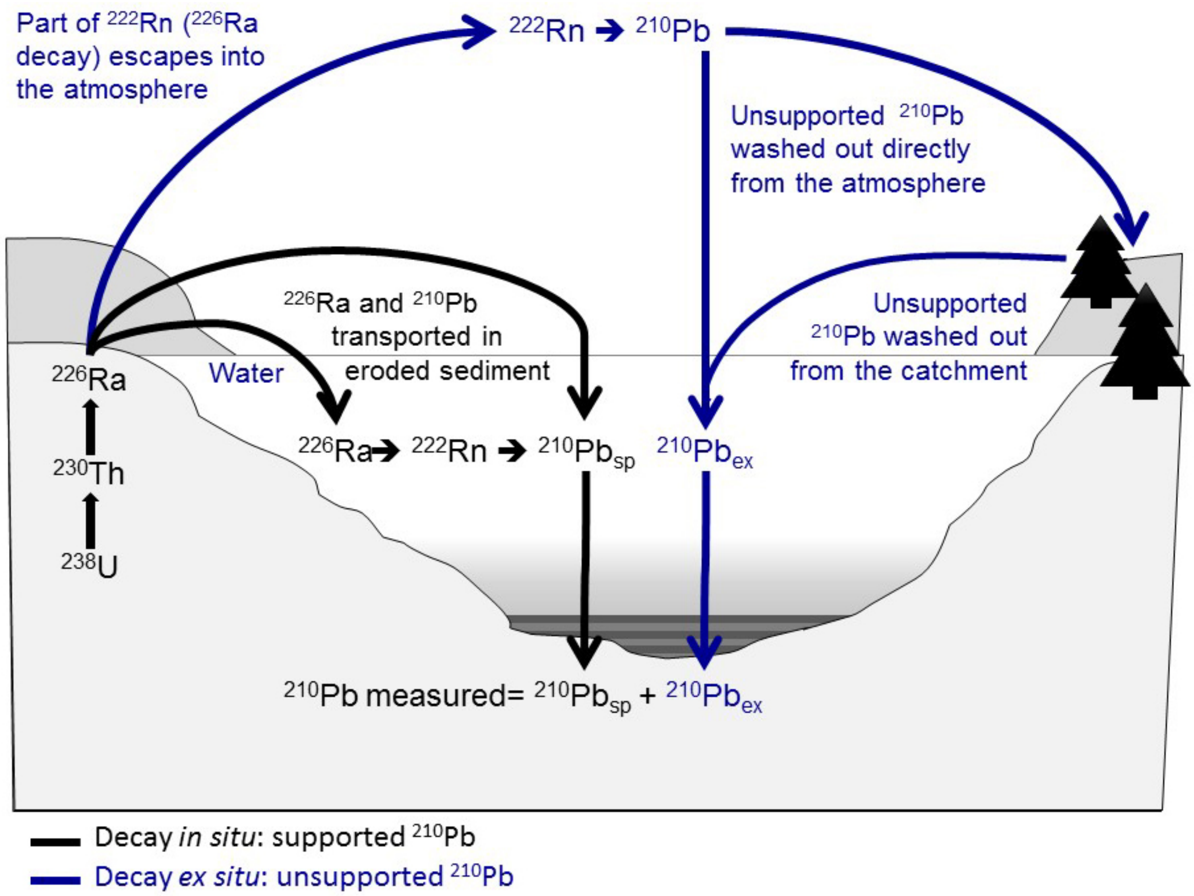

Figure 1: ^{210}Pb sources in lake or marine environments

The method is so well established that all geochronologist teams working on recent records confidently use it. The downside of its success is that there is a lack of information in most published age-depth models (Blaauw, 2010), as if mentioning the method certified the accuracy of the age model. While we are not questioning the validity of every published model, any field benefits from reproducibility of its results (Wilkinson et al., 2016). Establishing an age-depth model is the first step of any investigation on sediment sequences; therefore, ensuring that the hypotheses made at this stage are transparent is critical. Blaauw (2010) provided the *clam* R code to the palaeo-community to provide an easy, automated, transparent, documented and adaptable environment for producing age-models from ^{14}C sequences. Herein, we propose a systematic approach to producing chronologies for sediment cores using short-lived radionuclides ($^{210}Pb_{ex}$, ^{137}Cs and ^{241}Am) and different types of $^{210}Pb_{ex}$ models, based on the free and open-source software R. We first describe the different hypotheses for $^{210}Pb_{ex}$ decay and the resulting models; we then introduce the argument of the R function we developed, before applying the *serac* code to six complex case studies. We wish our code to supplement *clam* for chronologies for the past century.

3. Models for ^{210}Pb decay

3.1.Constant Flux Constant Sedimentation

The constant flux constant sedimentation rate (CFCS) model method is based on the hypothesis that there is neither mixing nor Pb diffusion in the sediment (Goldberg, 1963; Krishnaswamy et al., 1971). In a semilogarithmic diagram $^{210}Pb_{ex}$ activities relative to the depth have a linear relationship, as follows:

$$^{210}\mathrm{Pb}_{\mathrm{ex}}^{z} = {}^{210}\mathrm{Pb}_{\mathrm{ex}}^{0} \times e^{-\lambda t} \qquad \text{with} \qquad {}^{210}\mathrm{Pb}_{\mathrm{ex}} = {}^{210}\mathrm{Pb}_{\mathrm{mes}} - {}^{226}\mathrm{Ra}_{\mathrm{mes}} \; and \; t = z/SAR$$

$^{210}Pb_{ex}{}^{0}$ is the $^{210}Pb_{ex}$ activity at the sediment surface (t=0), λ is the decay constant for ^{210}Pb (Ln(2)/22,3; expressed in y^{-1}), z is the depth and SAR is the sediment accumulation rate expressed in ($mm.yr^{-1}$). Any instantaneous event has to be removed before computation (low $^{210}Pb_{ex}$ values). If a sedimentation rate changes in time (one or two times), it is still possible to use this model, but on each section of constant sedimentation rate.

Such a model could be applied with mass depth (m_z) instead of depth expressed in (g.cm^{-2}) and sedimentation rates are expressed as mass accumulation rates (MAR) in (g.mm^{-2}.y^{-1}), as follows:

$$m_z = \sum_{j=0}^{j=i} DBD_j \times \Delta z_j \quad with \quad DBD_j = \frac{\Delta m_j}{S\Delta z_j}$$

For this model we have to calculate the section dry bulk densities (DBD express in g.cm^{-3}); Δz is the section width and S is the core cross section (in cm^2). The CFCS model applied versus mass depth (by cluster or not) presents a very interesting alternative to CRS model (Abril, 2019; Tylmann et al., 2016).

3.2. Constant Rate of Supply

The constant rate of supply (CRS) model is based on the hypothesis that the flux of $^{210}Pb_{ex}$ (P) is constant, but the SAR varies with time (Appleby and Oldfield, 1978). As a result, the ^{210}Pbex activity decreases when sediment fluxes increase. This model defined the cumulative activity A(t) (mBq.cm^{-2}) during time t, corresponding to a depth z, as follows:

$$A(t) = \int_0^t P(t).\partial t$$

The $^{210}Pb_{ex}$ inventory can then be calculated by taking in account the decay of $^{210}Pb_{ex}$ over time, as follows:

$$I = P_0 \int_0^{\infty} e^{-\lambda t} \partial t = \frac{P_0}{\lambda} = \sum_{z=0}^{\infty} (^{210}Pb)_{ex}^{z}\, m_z$$

where $\sum_{z=0}^{\infty} (^{210}Pb)_{ex}^{z}\, m_z$ represents the ^{210}Pbex activity integrated over the sediment column and m_z is the dry mass depth of the measured section at z depth, express in g.cm^{-2}. If the section dry masses (m_Z) are not known, but we know those of the section DBD, the mass depths m_z can be calculated as follows:

$$m_j = DBD \times \Delta z_j$$

The use of this model assumes that all depths are measured (or interpolated) and that secular equilibrium is reached (i.e., no more $^{210}Pb_{ex}$ activities are observed in the deeper sample). The age (t_Z) at the depth Z is obtained by the equation, as follows:

$$t_Z = \frac{1}{\lambda} \times ln\left[\frac{\sum_{z=0}^{\infty}(^{210}Pb)_{ex}^{z}\, m_z}{\sum_{z=Z}^{\infty}(^{210}Pb)_{ex}^{z}\, m_z}\right]$$

where $\sum_{z=Z}^{\infty}(^{210}Pb)_{ex}^{z}\, m_z$ represents the $^{210}Pb_{ex}$ activity integrated below depth z.

When the CRS model is applied, a "too-old" age error described by Binford (1990) is always present for the deeper core sections. The "too-old" age error arises from underestimation of $^{210}Pb_{ex}$ and may result from analytical limitations, sampling strategy or both. This underestimation is that their $^{210}Pb_{ex}$ ages are older than their true ages, hence the name "too-old" age error. Thus, $^{210}Pb_{ex}$ dating based on the CRS model must be conducted with caution (Blais et al., 1995) or corrected for (Tylmann et al., 2016) to avoid "too-old" age error for deeper core sections (Binford, 1990).

3.3. Constant Initial Concentration

The constant initial concentration (CIC) model is based on the hypothesis that any changes in $^{210}Pb_{ex}$ or the sedimentation rate are synchronous and reversed so that the initial activity within the sediment remain constant (Pennington et al., 1976). The model relies on the following equation:

$$t_z = \frac{1}{\lambda} \times ln\left[\frac{210Pb_{ex}^{0}}{210Pb_{ex}^{z}}\right]$$

where t_z is the age at depth z, $^{210}Pb^{0}_{ex}$ is the activity at the surface of the sediment, and $^{210}Pb^{z}_{ex}$ is the activity at depth z. This model cannot be used if bioturbation has affected the sediment column or if an instantaneous event perturbed the $^{210}Pb_{ex}$ decrease profile (low $^{210}Pb_{ex}$ values).

Uncertainties in the CRS and CIC model derived ages are computed from equations from Sanchez-Cabeza and Ruiz-Fernández, (2012).

4. R code

We developed a package on the open-source software R (R Core Team, 2014). All input files must be saved in a tab separated '.txt' format, with periods as decimal delimiters. Table 1 illustrates typical data input. Depth top (depth_min) and bottom (depth_max) represent the sampling interval of each sample. The ^{137}Cs, ^{241}Am, and density columns are optional, but the latter (density) is required for inventory calculations, CFCS mass depth calculations and the CRS model. Even if all depths were not analysed for short-lived radionuclides, all depths and corresponding densities are emplaced in the input file to not extrapolate density data (NA in Table 1), which could present different patterns in regard to their different environmental systems. If density data is not available, the analysed depths are sufficient for age modelling (except for the CRS model). The input file must be placed in a sub-folder of the Cores folder, e.g., *serac\Cores\MyCore\MyCore.txt* and the R working space must be in *serac*.

The function *serac_input_formatting('MyCore')* can be used to help format the input file. To use it, place the raw input file (column names in first row, data starting from the second row) in the folder as described above. This function asks the user to identify columns, rename them, and replace the input data file automatically.

The package can be downloaded from the GitHub repository https://github.com/rosalieb/serac, or with the package devtools (Wickham et al., 2018) and the code:

```
library(devtools)
devtools::install_github("rosalieb/serac", build_vignettes = TRUE)
library(serac)
```

Table 1. *serac* input file for an example (Lake Iseo). Units are given as an indication, but should not be included in the input file to prevent any issues with file reading. * indicates input data that are optional. NA correspond to missing data: we recommend including continuous density data as $^{210}Pb_{ex}$ can be interpolated (or depth not considered) if needed, while density cannot.

depth_min (mm)	depth_max (mm)	density* (g/cm3)	Pb210ex (Bq/kg)	Pbex210_er (Bq/kg)	Cs137* (Bq/kg)	Cs137_er* (Bq/kg)	Am241* (Bq/kg)	Am241_er* (Bq/kg)
0	6	0.059	370	8	18.1	0.5	0.6	0.3
6	11	0.042	414	11	25.5	0.8	0.2	0.4
11	17	0.048	381	9	26.9	0.7	0.3	0.3
17	22.5	0.065	322	11	29.9	0.8	0.2	0.35
22.5	27.5	0.074	284	7	43.7	0.8	0.6	0.3
27.5	40.5	0.063	247.5	NA	NA	NA	NA	NA
40.5	48	0.052	211	8	77.5	1	0	0
48	54	0.053	249.5	NA	NA	NA	NA	NA
54	58.5	0.054	288	9	233	1.9	0.4	0.35

58.5	64.5	0.055	232	8	631	2.7	0.27	0.4
64.5	70.5	0.069	225	NA	NA	NA	NA	NA
70.5	75	0.082	218	9	1305	5	3.307	0.7
75	83	0.055	166	6	67.1	1	0.1	0.3
83	88.5	0.079	143	NA	NA	NA	NA	NA
88.5	95	0.065	120	6	38.4	0.6	0.7	0.25
95	101	0.057	139	NA	NA	NA	NA	NA
101	111	0.048	158	7	26.7	0.6	0.26	0.26
111	119	0.049	156	NA	NA	NA	NA	NA
119	130	0.050	154	6	47.9	0.8	1.2	0.3
130	139.5	0.072	129	6	155.6	1.5	3.79	0.4
139.5	150	0.087	88	5	96	0.9	1.09	0.29
150	159.5	0.101	96	6	61.6	1	1.1	0.4
159.5	164	0.107	82	6	19.1	0.4	0.55	0.28
164	173	0.097	63	6	7.7	0.3	0.14	0.3
173	179.5	0.107	55.5	NA	NA	NA	NA	NA
179.5	187.5	0.117	48	5	2.4	0.2	0.3	0.3
187.5	199.5	0.107	47	NA	NA	NA	NA	NA
199.5	209	0.106	46	3	0.7	0.1	0.2	0.16
209	234	0.107	40	NA	NA	NA	NA	NA
234	244.5	0.108	34	5	0.5	0.1	0	0
244.5	254	0.107	34	NA	NA	NA	NA	NA
254	264	0.105	34	5	0.23	0.14	0	0
264	283.5	0.108	31	NA	NA	NA	NA	NA
283.5	295	0.110	28	3	0.7	0.1	0	0
295	305	0.110	23	NA	NA	NA	NA	NA
305	317	0.109	18	4	0.19	0.13	0	0

The code includes the sedimentation hypotheses described in the previous section (CFCS, CRS, and CIC). The only requested arguments are the name of the core (must be the same of the folder and the data input) and the coring year. All other arguments have default values and do not have to be filled on the first run. Some arguments are logical (i.e., TRUE or FALSE), other are entered in the form of vectors (e.g., list of sedimentation hypotheses, upper and lower limits for instantaneous deposits). All depths must be entered in millimetres.

Table 2 summarises the main options; the case studies included in the next section showcase different scenarios. A 'cheat sheet' summarising the steps and main functions is available in Supplementary Materials 1.

Table 2. Main options included in *serac*. Refer to Supplementary Material 2 for complete list of functions.

Category	Description
Site ID	**Only two arguments are mandatory to run the code: the name of the core and the coring year. Other arguments have default values that can be used**. The name of the core has to match the folder name and the file name with the input data.

$^{210}Pb_{ex}$	The user can choose to plot $^{210}Pb_{ex}$ measurements, with or without potential instantaneous deposits. One of the three models can be visualised. The choice to include or not include instantaneous deposits will automatically remove the corresponding measurements.
^{137}Cs	The user can choose to plot ^{137}Cs, and if so, to identify Chernobyl, the fallouts from nuclear war tests, and the firsts fallouts (logical arguments).
^{241}Am	The user can choose to plot ^{241}Am and identify the fallouts from nuclear war tests
Model	List of model(s) the user wants to test. Choice among CFCS, CRS, CIC.
Photo	A photo of the sediment sequence can be added, upon precision of the upper and lower limit of the core (in mm). The photo will be automatically cropped.
Instantaneous deposit	Instantaneous deposits (flood, earthquake, slump layers) that should be excised can be added with this argument.
Ignore	For several reason, the user may want to ignore a measurement that is not part of an instantaneous deposit. This can be managed with this argument.
Sedimentation change	Up to two changes in the sedimentation rate can be tested. The depths of the changes are added in a vector.
Plot options	The user can choose whether to export the age-depth model figure using logical arguments. Colours and character size can also be modified.
Historic events	Historical events (e.g., flood, construction of a dam…) can be plotted on the last window.
Supplementary descriptor(s)	Up to two supplementary descriptors can be plotted. If done, an additional input file with these data should be included in the working folder.
Varves	Varve counting can be added on the age-depth model plot. If done, an additional input file with depths (in mm) and corresponding years must be included in the working folder.
Surface Mixed Layer	A depth in mm above which the sediment is considered to be mixed.
Mass depth	Logical (TRUE/FALSE) argument, to decide whether radionuclides should be plotted against mass accumulated depth. Default entries for sediment changes ignore instantaneous deposits and surface mixed layers, are in mm. Another argument (input_depth_mm) allows these depths to be entered in $g.cm^{-2}$ when turned to FALSE.

5. Case studies

5.1. *Lake Bourget* – A classic situation with only one model (CFCS) and one instantaneous event

Lake Bourget (45°44.7420N, 5°51.6850E) is a large lowland hard-water lake in the Northern French Alps, 18 km long and 2.8 km wide. This core was sampled in the deepest part of the lake at 145 m water depth and records of recent eutrophication (Giguet-Covex et al., 2010). Using *serac*, it is possible to calculate SAR = 3.849 mm.y^{-1} from short-lived radionuclides data on this core and provide age modelling at a higher resolution than the initial stepout (determined by *stepout*, e.g., 1 mm in the example below). The example below includes $^{210}Pb_{ex}$ CFCS models, ^{137}Cs and ^{241}Am peaks, varve counting with the identification of an instantaneous deposit linked to a historical earthquake (Figure 2) with the following arguments:

```
serac(name="LDB",coring_yr=2004,model=c("CFCS"),plotphoto=TRUE,minphoto=c(0),maxphoto=c(370),plot_Pb=T,plot_Pb_inst_deposit=T,plot_Cs=T,plot_Am=T,Cher=c(75,85),Hemisphere=c("NH"),NWT=c(172,180),FF=c(220,230),inst_deposit=c(197,210),historic_d=c(197,210),historic_a=c(1958),historic_n=c("earthquake 1958"),varves=T,plotpdf=T,stepout=1)
```

Details on the several arguments are available in Supplementary Material 1.

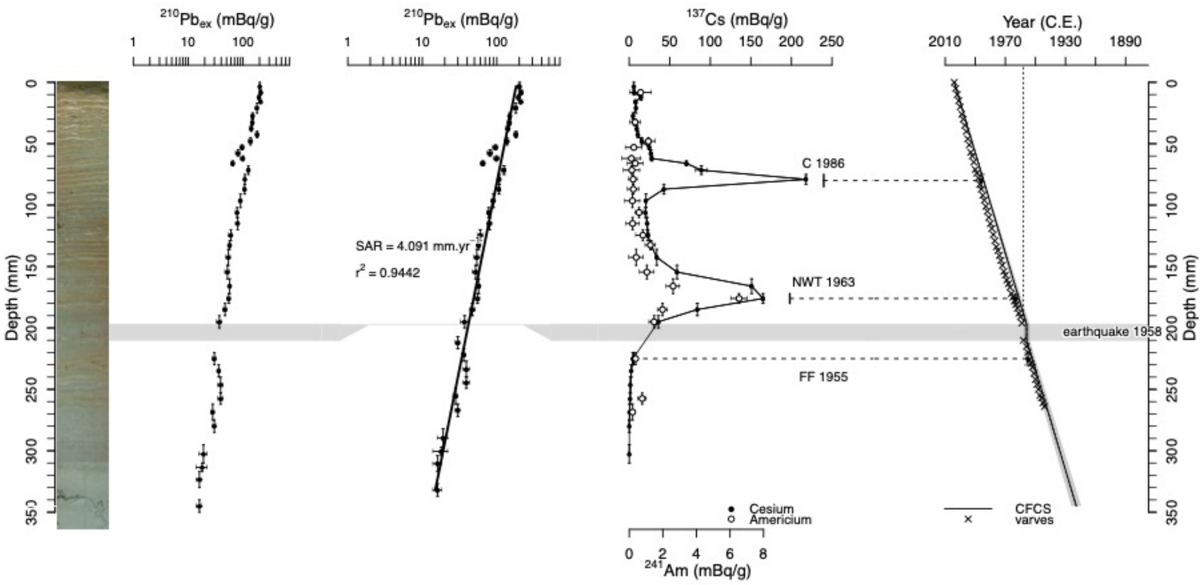

Figure 2. Age model derived from the *serac* function with, from left to right: core photo, ^{210}Pbex, ^{210}Pbex corrected of instantaneous deposits, ^{137}Cs and ^{241}Am activities and the CFCS age model with varve counting, ^{137}Cs and ^{241}Am peaks and the identification of the 1958 earthquake

5.2. *Lake Iseo* – An example of a sediment sequence where the three sedimentation hypotheses could be tested. Varve counting is also available.

Lake Iseo (45°44.205’N; 10°4.340’E) is a large lowland lake in Northern Italy 25 km long and 60.9 km^2 in surface area. This core is a sample from the Monte Isola plateau at approximately 70 m depth and contains evidence for a recent eutrophication (Rapuc et al., 2018). From short-lived radionuclides data on this core (Table 1), SAR = 3.157 mm.y^{-1}. In the script below, note that we request to visualise all three $^{210}Pb_{ex}$ models, ^{137}Cs and ^{241}Am peaks and varve counting (Figure 3) and we use a 5 mm resolution for our interpolated model.

```
serac(name="Iseo",coring_yr=2010,model=c("CFCS","CIC","CRS"),plotphoto=TRUE,minphoto=c(0),maxphoto=c(320),plot_Pb=T,plot_Am=T,plot_Cs=T,Cher=c(70,75),Hemisphere=c("NH"),NWT=c(130,140),FF=c(164,173),varves=TRUE,plotpdf=T,stepout=5)
```

The comparison between varve counting, artificial radionuclides and the ^{210}Pbex model shows that the CFCS model is preferable for this core and that there is evidence for the “too-old” age error described first by Binford (1990) for the CRS model in the deeper core sections and now widely observed (Abril, 2019; Tylmann et al., 2016, 2013). The “too-old” age error arises from an underestimation of ^{210}Pbex in deeper core sections in relation to analytical limitations, sampling strategy or both.

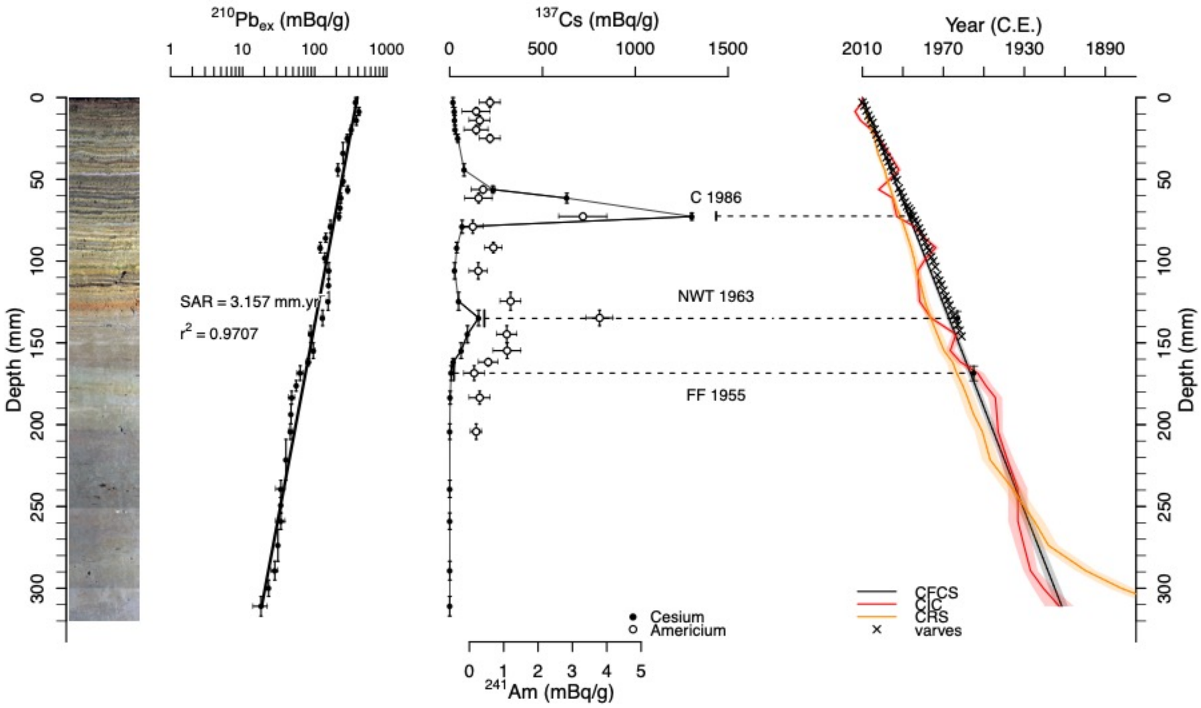

Figure 3. Age model derived from the *serac* function, from left to right: core photo, $^{210}Pb_{ex}$, ^{137}Cs and ^{241}Am activities and age model (CFCS, CIC, CRS) with varve counting and ^{137}Cs and ^{241}Am peaks.

5.3.Lake Luitel – an example of sediment sequence plot versus mass depth

Lake Luitel (FR) is a very small system (1.94 ha) located 1262 m above sea level, in a depression within the crystalline Belledonne range bedrock (Western Alps). The lake colour is black, typical of organic rich water and is encircled by bog type vegetation. An 80-cm-long core (LUI12P1) was collected from the deeper part of the lake (6 m) in 2012 to reconstruct the history of multiple industrial and urban mercury (Hg) emissions (Guédron et al., 2016).

This lake is rich in organic matter and thus presents a large amount of poral water; the classic CFCS model does not match the ^{137}Cs fallouts well (note that ^{241}Am was under the detection limit and is thus not presented in Figure 4). In such a lake system, a semilogarithmic plot of $^{210}Pb_{ex}$ activities versus mass depth allows us to consider density variations in regard to sediment compaction (Abril, 2019; Tylmann et al., 2016). We thus plot the CRS, CIC and CFCS models based on the mass depth model (Figure 4). The MAR is well defined ($0.047\ g.mm^{-1}.y^{-1}$, $r^2=0.975$) and the age model is in good agreement with the 1955 and 1963 AD ^{137}Cs markers and at lesser extent with the Chernobyl fallout. The CRS model also provides a reliably good age model in regards to the ^{137}Cs data, but still present too old ages for the deeper samples. The CIC model displays several ages inversions, which we want to avoid. The best age modelling is done thanks to *serac* and includes the CFCS mass depth calculation with the following arguments:

```
serac(name="LUI",coring_yr=2012,model=c("CFCS","CIC","CRS"),mass_depth=T,plotphoto=T,minphoto=c(0),maxphoto=c(470),plot_Pb=T,plot_Cs=T,Cher=c(115,125),Hemisphere=c("NH"),NWT=c(285,295),FF=c(305,315),plotpdf=TRUE)
```

Note that the ^{137}Cs peaks (or other depth-related arguments) could be identified in the *serac* function in mm by default or in g.cm^{-2} if we add the argument *input_depth_mm = F*.

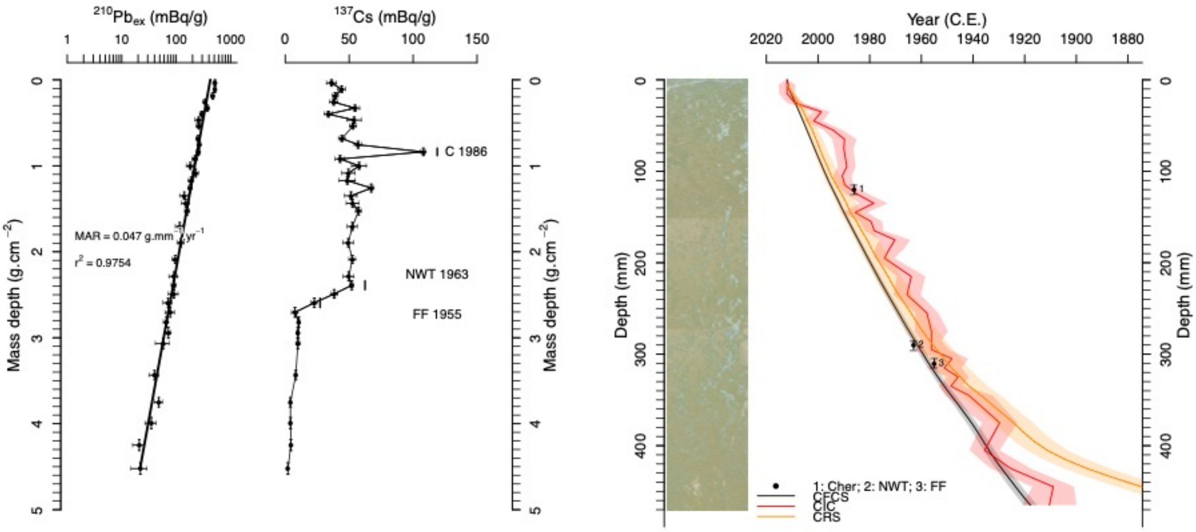

Figure 4. From left to right: ^{210}Pbex activities, ^{137}Cs activities, photo of the core, and the age models (CFCS_mass_depth, CRS, CIC) for the Lake Luitel sediment core. Note that in the left and central parts, data are plotted versus mass depth, while in the right part, data are plotted versus depth.

5.4. *Lake Saint André* – an example of sediment sequence with changes in the sedimentation rate

Lake Saint André (FR) is a relatively small system (7.64 ha), formed in 1248 after a large landside. Vineyards have occupied approximately 36% of its 48.5 ha watershed since the beginning of World War II. A 1-m core (SAN11P2) was collected from the deepest part of Lake Saint André (12 m) in 2011 to investigate long-term succession and the diffuse transfer of herbicides, fungicides, and insecticide treatments (Sabatier et al., 2014).

A logarithmic plot of $^{210}Pb_{ex}$ activity (Figure 5) shows a general decrease with three distinct linear trends. According to the (CFCS) model applied to each part of the profile, we can define mean accumulation rates of 2.9 ± 0.2 $mm.y^{-1}$ between depths of 41 and 26 cm, 5.3 ± 0.6 $mm.y^{-1}$ between 26 and 16.5 cm, and 8.6 ± 1.3 $mm.y^{-1}$ in the upper 16.5 cm of the core (3). ^{137}Cs and ^{241}Am activities (3) are in good agreement with the ages derived from the $^{210}Pb_{ex}$-CFCS model and support the interpretation of two primary sedimentation rate changes in ~1973 ± 5 y and 1994 ± 2.5 y. These two changes in the sedimentation rate are related to vineyard practices increasing erosion in the watershed during two periods: (1) in the early 1970s, with the local use of heavy farm machinery and (2) in the early 1990s, with increasing applications of postemergence herbicides (Glyphosate, see Sabatier et al., 2014 for more details). The age modelling conducted through *serac,* including the two changes in sedimentation rate, takes the following arguments:

```
serac(name="SAN",coring_yr=2011,model=c("CFCS","CIC","CRS"),plotphoto=TRUE,minphoto=c(0),maxphoto=c(420),plot_Pb=T,sedchange=c(165,260),plot_Am=T,plot_Cs=T,Cher=c(195,205),Hemisphere=c("NH"),NWT=c(275,295),FF=c(315,325),plotpdf=TRUE,archive_metadata=T)
```

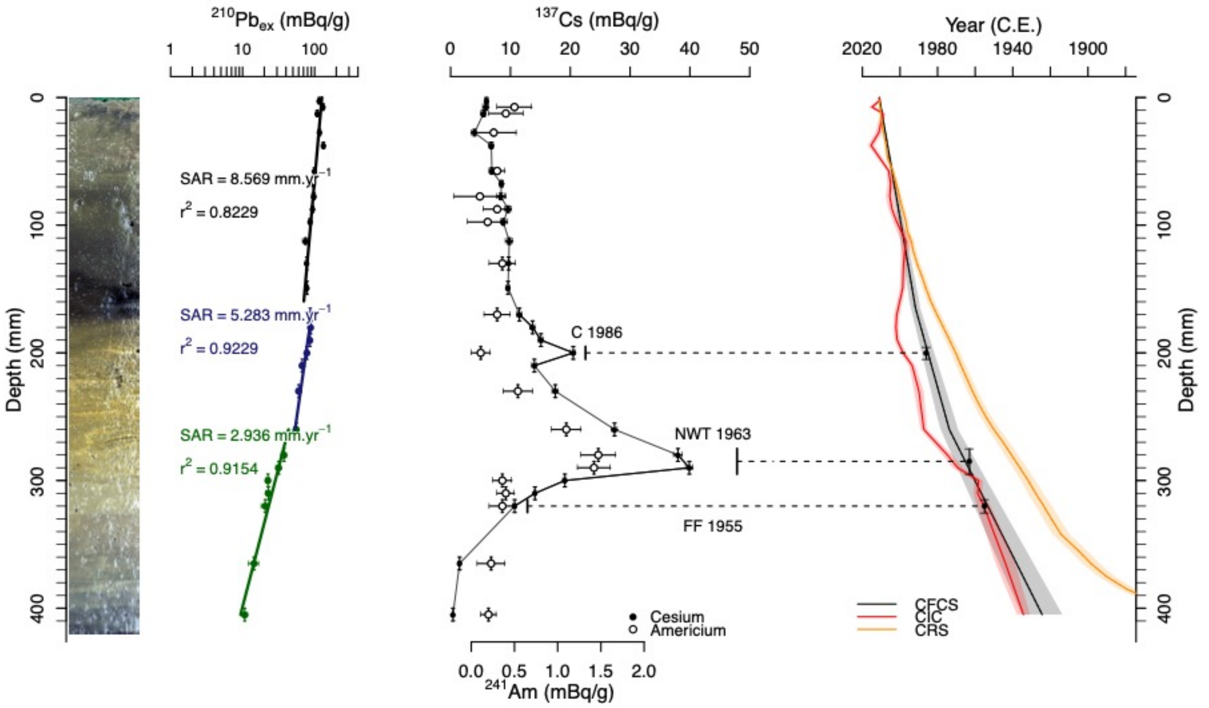

Figure 5. From left to right: photography, $^{210}Pbex$ activity, ^{137}Cs and ^{241}Am activities, and the age model (CFCS, CRS, CIC) for the Lake Saint André sediment core.

5.5. Lake Allos – an example of a sediment sequence with instantaneous deposits

Lake Allos is a high-altitude lake in the French Alps (2230 m a.s.l., 0.6 km^2). Half of the 5-km^2 catchment is drained by three permanent torrents that transport terrigenous flows towards the lake mainly during extreme precipitation events (Wilhelm et al., 2015, 2012). A plot of $^{210}Pb_{ex}$ activity (Figure 6) shows a general decrease with low activities at several depths that correspond to graded beds. To illustrate these sedimentary events, we add one to two supplementary descriptors (*suppdescriptor*) to the age model figure, such as geochemical data (XRF). Ca enrichment associated with coarser grain size evidence four instantaneous deposits in the Allos sediment sequence, indicating a large input from the watershed, while Fe content is associated with continuous sedimentation (Figure 6, see Wilhelm et al., 2012 for more details). As these events are instantaneous, there are removed before computing the CFCS model, which assumes a linear sedimentation rate. In this case, $^{210}Pb_{ex}$ activities, corrected for instantaneous deposits, show a change in the mean sedimentation rate at 71 mm. The final age model is supported by the ^{137}Cs and ^{241}Am activities and by historical floods that correspond to these four instantaneous events. These floods deposits are also added in Figure 6 to validate the chronology. The age modelling is conducted through *serac* and includes the historical events and one change in sedimentation rate with the following arguments:

```
serac(name="ALO09P12",coring_yr=2009,model=c("CFCS","CRS"),plotphoto=TRUE,minphoto=c(0),maxphoto=c(210),plot_Pb=T,plot_Pb_inst_deposit=T,inst_deposit=c(20,28,100,107,135,142,158,186),sedchange=c(71),plot_Am=T,plot_Cs=T,Cher=c(35,40),Hemisphere=c("NH"),NWT=c(51,61),suppdescriptor=TRUE,descriptor_lab=c("Ca (cps)","Fe (cps)"),historic_d=c(20,28,100,107,135,142,158,186),historic_a=c(1994,1920,1886,1868),historic_n=c("sept 1994 flood","1920 flood","1886 flood","1868 flood ?"), min_yr=c(1750),dmax=c(180),plotpdf=TRUE)
```

Note that for larges figures as Figure 6, R may sometimes not create the preview (and gives an error) because the plotting window is too narrow. The user can try to extend the plotting zone (which is easy in RStudio, RStudio Team, 2016). We added a logical argument, *preview*, which can be turned to FALSE to address this issue; in this case, the preview is simply not displayed. If the argument *plotpdf* is left to its default value, i.e., TRUE, the figure will still be created in the core subfolder.

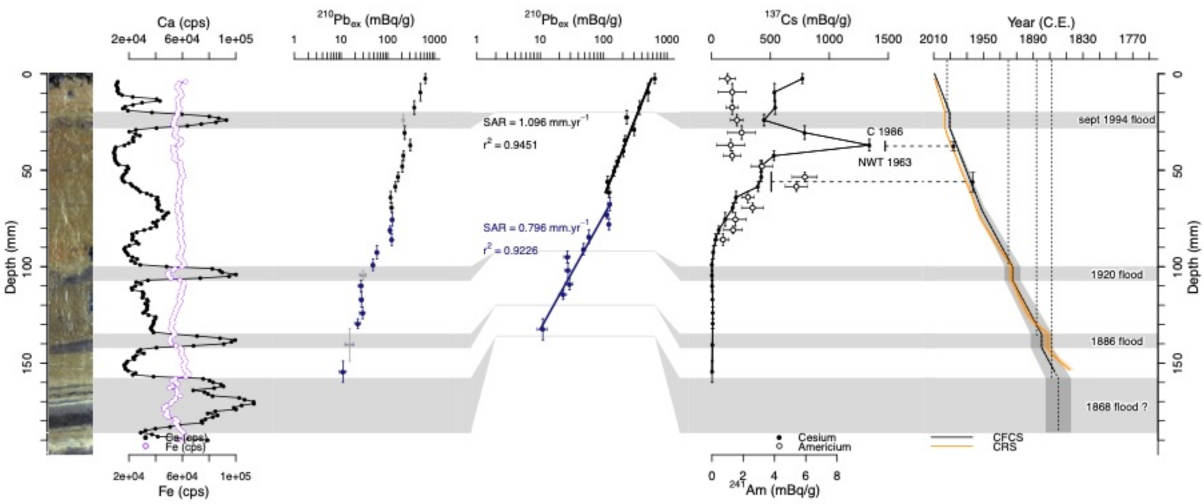

Figure 6. From left to right: core photograph, Ca/Fe ratio and raw Fe, $^{210}Pb_{ex}$ activity with and without instantaneous deposit events, ^{137}Cs activity and ^{241}Am activity, and the age model for the Lake Allos sequence. The horizontal grey lines indicate layers that were identified as instantaneous events.

5.6. *Pierre Blanche lagoon* – An example of a sediment sequence with a surface mixed layer

The PB06 core (7.9 m) was collected in the Pierre Blanche Lagoon (PBL), in the southern part of the Palavasian lagoonal complex (France) in 2006 (Sabatier et al., 2010b). This coastal shallow water environment contains many organisms that induce bioturbation, with advection-diffusion in the upper first centimetres in the deepest regions caused by mollusc and gallery-diffusion by worms (François et al., 2002). This second process is difficult to identify and to correct for (Sabatier et al., 2010a). The resolution of the advection-diffusion model (Sharma et al., 1987) by Lecroart *et al.* (2007) applied to $^{210}Pb_{ex}$ allows the estimation of SARs and the biodiffusion coefficient (D_b). We can thus define a surface mixed layer (SML) within which $^{210}Pb_{ex}$ activities are perturbed; PB06 has almost constant activities in the first 3 cm (Figure 7). The $^{210}Pb_{ex}$ activities profile is thus composed of a bioturbated upper part, characterised by a combination of sedimentation and bioturbation (SAR, D_b) and below which a non-perturbed profile exists where D_b= 0. To solve this model, we can calculate a mean sedimentation rate for the non-bioturbated part and if we suppose that the sedimentation rate remains constant, we can extrapolate this estimate to the upper part. With *serac* we must define the SML to calculate sedimentation and create a CFCS age model. It is not possible to apply the CIC model in this case because the initial activity is perturbed. The age model for PB06 is also constrained by the ^{137}Cs peaks and a historical storm event identified by geochemical data (Figure 7); for more details see Sabatier et al. (2010c). The age modelling is conducted using *serac* and includes the SML with the following arguments:

```
serac(name="PB06",coring_yr=2006,model=c("CFCS","CRS"),plotphoto=TRUE,minphoto
=c(0),maxphoto=c(350),plot_Pb=T,plot_Pb_inst_deposit=T,inst_deposit=c(315,350),SML
=30,plot_Cs=T,Cher=c(50,60),Hemisphere=c("NH"),NWT=c(100,120),suppdescriptor=T,
descriptor_lab=c("Si/Al"),historic_d=c(315,350),historic_a=c(1893),historic_n=c("1894
storm"),min_yr=1870,dmax=c(350),plotpdf=TRUE)
```

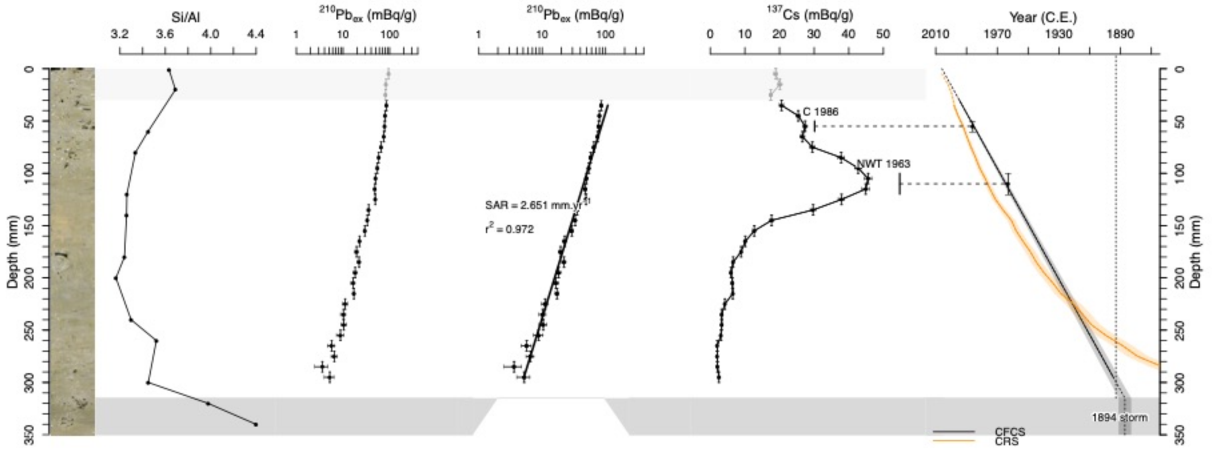

Figure 7. From left to right: core photograph, Si/Al content, $^{210}Pb_{ex}$ activities, ^{137}Cs activities, and the age model (CFCS and CRS).

The comparison among historical events (storms), artificial radionuclides and the $^{210}Pb_{ex}$ model results in the CFCS model being preferable to the CRS for this core and evidence of the "too-old" age error described by Binford (1990) for the CRS model in the deeper core sections, resulting from the 1894 storm event.

6. Metadata

Every time the code is run, a metadata file is automatically generated in the folder. The metadata file summarises the main decisions made by the user (e.g., presence/absence of instantaneous deposit, type of model chosen) but also other general information on the user (ORCID, affiliation, email) and the core (ISGN: International Geo Sample Number (IGSN)/System for Earth Sample Registration Database (www.geosamples.org, measurement laboratory, measurement method, date of measurement). These data are entered independently from the exploration phase of the model through the function user_infos() and core_metadata(). The former function theoretically needs to be used only once by each new user the first time the library *serac* is used. The new user will be required to answer several questions (affiliation, ORCID number, etc.). These information are then integrated into the metadata file associated with the age modelling, in text format. The core_metadata() function ask more details about the core itself and the analytical data, summarised in Table 2 and will be enter according to the following lines:

core_metadata(name="Mycore")

These data can also be directly implemented during the age modelling phase by adding archive_metadata=T in the *serac* function. The metadata listed in Table 3 emerges from both data reports of radioactivity detections from the CNRS in France (Centre National de la Recherche Scientifique) and a recent international survey (literature review and questionnaire) about ^{210}Pb metadata (Courtney Mustaphi et al., 2019). The French initiative coordinated the development of a common way to present short-lived radionuclides data through the ROZA (Rétro-observatoire Archives sédimentaires des Zones Ateliers) experience and produced a document guiding the information needed to store data in a repository. The review by Courtney Mustaphi et al. (2019) also suggests a set of minimum reporting guidelines for ^{210}Pb metadata and data needed to improve data archiving standards to facilitate data reutilisation.

Table 3. Example of metadata associated with the SAN core (Sabatier et al., 2014)

Parameters	Example
ISGN	EDYSAN001
sample date	2011-12-01
coring coordinates y	45.494980
coring coordinates x	5.985720
coring method	gravity corer
laboratory subsampling method	calibrated volumetric sampler
measurement laboratory	LSM/EDYTEM, FR
instrument type	well-type germanium detector
measurement startdate	2012-01-15
measurement enddate	2012-04-05
additional comments	^{210}Pb background reached

These two functions and all parameters inside are optional but we encourage the users to use these functionalities as they help generate a more exhaustive background for the core.

Note that another text file is automatically generated and incremented with all new tests. The file is found in the core folder (~\Cores\MyCore\serac_model_history_MyCore.txt). It (1) provides a history of attempts and (2) displays a message in R if a code has been tested previously. A vigilant user can then compare and trace back the logical thinking that led to the final model.

7. Discussion

serac provides a rapid yet exhaustive tool for testing sedimentation hypotheses and creating age models for the last century. Several functions (Table 4) guide the user in building age-depth models for a given core. To choose the best chronology for the studied archives, *serac* allows different age models to be compared versus depth or mass depth with other independent markers such as artificial radionuclides fallout or historic events. $^{210}Pb_{ex}$ models are sometime used incorrectly. For instance, if the CIC model is used for a core that has instantaneous deposits with lower $^{210}Pb_{ex}$ activities or a surface mixed layer linked to bioturbation processes; or if the CRS model is used when the $^{210}Pb_{ex}$ inventory is not the total (activities were not measured until secular equilibrium existed between ^{210}Pb and ^{226}Ra). With *serac,* the sedimentation hypotheses have to be satisfied and if they are not tested, an error message will be automatically provided, explaining why. In that respect, *serac* is also a pedagogic tool. Using *serac* easily allows reproducibility of the main hypotheses behind any age-depth model (such as changes in sedimentation rates or the presence of instantaneous deposits). We believe that the availability of a user-friendly code on an open source platform to visualise and test sedimentation hypotheses is an important step towards reproducibility. *serac* allows users customisation of parameters to include, as well as cross-platform support (Windows, Linux, Macs).

Furthermore, if the density is present in the input data, *serac* generates the ^{210}Pb and ^{137}Cs inventories of sediment cores, which provides the opportunity to compare these values between sites to map radionuclide fallouts. For instance, ^{137}Cs inventories of Lake Iseo (1390 Bq.m^{-2}; range: 1380-1403 Bq.m^{-2}) and Lake Bourget (975 Bq.m^{-2}; range: 953-997 Bq.m^{-2}) reported the same age of 2020, but present significant differences related to the higher Chernobyl accident fallout in Italy relative to that in France. The R code of *serac* can be understood relatively easily and could be adapted to fit user preferences. Output files (age model, metadata, figure) could be used (1) in the current form or integrated in a larger age model such as *clam* (2) to create a figure for publication and (3) in data saving platforms with general information on data, metadata, the age modeller, and the age model parameters, which would allow data tractability and reproducibility. It is hoped that *serac* could help the palaeoscience community standardise and enhance future age depth models that use sort-lived radionuclides and allow the extension of the data lifecycle (Wilkinson et al., 2016).

Table 4. Summary of the functions around *serac*, for a core named 'MyCore'.

Function	Use	Output
user_infos()	New users run this function once to enter professional details	A .txt file in the ~\Cores folder with user's metadata
core_metadata(name = 'MyCore')	Before running serac, but once a folder 'MyCore' had been created in the ~\Cores folder, this function questions the user on metadata specifically related to the core (see Table 3 for details)	A serac_metadata_suppmetadata.txt file in the ~\Cores\MyCore folder This supplementary data will be included to the general metadata after each model computation.
serac_input_formatting(name = 'MyCore')	Input data file can be formatted outside R. This function can help correct several errors (columns names, unit for depth, density calculation, etc.)	Replace MyCore.txt in the ~\Cores\MyCore folder by a correctly formatted file and save the raw data in the same folder under the name MyCore_raw.txt
serac(name = 'MyCore', coring_year = 2019)	**Main age-depth model computation function. Refer to** Table 2 and case studies	Generate a plot in the ~\Cores\MyCore folder (if *plotpdf=TRUE*), a metadata file, and depth-age correspondence (raw and interpolated, according to resolution chosen by the *stepout* argument) for each type of model selected in the *model* argument.
serac_map()	*Function not describe in this paper – if GPS coordinates are given for the different cores (through the core_metadata() function), serac_map() will generate a map with the location of the different sites around the world*	A world map with the location of the different study sites

8. Acknowledgements

We thank A.-L. Develle and W. Rapuc for beta testing previous versions of *serac* and C. Pignol for recommendations on metadata outputs through the ROZA (Rétro-observatoire Archives sédimentaires des Zones Ateliers) experience at the CNRS (Centre National de Recherche Scientifique français).

9. Data Availability

Data to reproduce the example for Lake Allos (Figure 6) are accessible through the package.

10. References

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11. Supplementary material 1

serac cheat sheet

1

Using the library devtools, install serac: `devtools::install_github("rosalieb/serac", build_vignettes = TRUE)`

Step 1 User information – optional, fill it only once or when your affiliation / details change `user_infos()`

2

Step 2.1 Core analysis

1. Photo.
2. XRF core scanner – potential supplementary descriptors.
3. Sediment characterization: granulometry, wet weight, LOI, density – potential supplementary descriptors.
4. Radionuclides measurements.

Step 2.2 Prepare the input files

For a given core named "MyCore", user should have in a given working directory "MyWD":

~/MyWD/Cores/MyCore/…

- MyCore.txt* — radionuclides data
- MyCore.jpg — core photo
- MyCore_varves.txt — varves
- MyCore_proxy.txt — additional proxies

(* means mandatory, txt files with tab separators)

Function below helps editing the MyCore.txt file:

```
serac_input_formatting(name="MyCore")
```

MyCore.txt should have the following column names and units:

Column name	Description (unit)
depth_top	alt. name: depth_min (mm)
depth_bottom	alt. name: depth_max (mm)
density	($g.cm^{-3}$)
Pbex	Unsupported Lead 210 excess ($Bq.kg^{-1}$)
Pbex_er	Error $^{210}Pb_{ex}$ ($Bq.kg^{-1}$)
Cs	Cesium 137 ($Bq.kg^{-1}$)
Cs_er	Error ^{137}Cs ($Bq.kg^{-1}$)
Am	Americium 241 ($Bq.kg^{-1}$)
Am_er	^{241}Am ($Bq.kg^{-1}$)

Optional: enter metadata for this core

```
core_metadata(name="MyCore")
```

Step 2.3 Model computation

List of arguments included in the main function:

```
args(serac)

?serac

serac(name, coring_yr, model, Cher, NWT, Hemisphere, FF,
inst_deposit, input_depth_mm, ignore, mass_depth, plotpdf,
preview, plotphoto, minphoto, maxphoto, Pbcol,
inst_depositcol, modelcol, historic_d, historic_a,
historic_n, historic_test, suppdescriptor, descriptor_lab,
plot_Am, plot_Cs, plot_Pb, plot_Pb_inst_deposit,
plot_CFCS_regression, varves, dmin, dmax, sedchange,
min_yr, SML, stepout, mycex, archive_metadata, save_code)
```

MAKE SURE YOUR WORKING DIRECTORY IS THE GOOD ONE (i.e., the one with the 'Cores' folder)

```
getwd() ; setwd("~/MyWD")
```

Compute model:

```
Model1 <- serac(name="MyCore", coring_year=2019)
```

A list is created - explore this object with the following functions:

```
class(Model1)
[1] list
names(Model1)
[1] Output depends on which model was selected
```

Step 2.4 Compare output with prior knowledge (from step 2.1)

Low fit OR potential changes in sedimentation rate OR potential instantaneous deposit OR warning messages that could be addressed

↓

Go back to step **2.3** and edit code

Best model, good agreement between $^{210}Pb_{ex}$, ^{137}Cs, and historical events, all changes in sedimentation rate or wet weight/density have been addressed

↓

Done!

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Step 3 Understand the output files

Running serac created some files in the ~/MyWD/Cores/MyCore/ folder.

File	What it is
serac_model_history_MyCore.txt	History of the code combination you tried.
serac_metadata_suppmetadata.txt	File created with the function "core_metadata("MyCore"). Fill it in once when you get the core, then carry on with model tests.
MyCore.pdf	If plotpdf=TRUE (default), the model is automatically generated in the folder.
MyCore_Metadata_YYYY-MM-DD.txt	Metadata and output regarding the model you computed. A file you would typically share with your colleagues, or include as Appendix to a manuscript submission.
MyCore_CFCS.txt (.csv) MyCore_CFCS_interpolation.txt (.csv)	Dated depth if CFCS model was chosen, and interpolated model with intervals determined by stepout (default to 5 mm).
MyCore_CIC.txt (.csv) MyCore_CIC_interpolation.txt (.csv)	Dated depth if CIC model was chosen, and interpolated model with intervals determined by stepout (default to 5 mm).
MyCore_CRS.txt (.csv) MyCore_CRS_interpolation.txt (.csv)	Dated depth if CRS model was chosen, and interpolated model with intervals determined by stepout (default to 5 mm).

12. Supplementary material 2

Argument	Default	Description
Name	Mandatory argument e.g., name=" ALO09P12"	Name of the core, given using quotes. Defaults to the core provided with serac. Use preferably the published name of the core for traceability.
coring_yr	Mandatory argument e.g., coring_yr=2009	Coring year
model	model=c("CFCS")	Select 1 to 3 item between c("CFCS", "CIC", "CRS"). If several models are selected, they will all be plotted together in the last window.
Cher	Cher=NA	If ^{137}Cs measurement were done, where do you detect the Chernobyl peak? The argument is a vector of two depth given in millimetres giving the top and bottom threshold for the 1986 Chernobyl event. The user can run the model without giving any specification before making a decision. In such case, leave the argument empty.
NWT	NWT=NA	If ^{137}Cs measurement were done, where do you detect the Nuclear Weapon Test peak? The argument is a vector of two depth given in millimetres giving the top and

		bottom threshold for the 1960s Nuclear Weapon Test event. The user can run the model without giving any specification before making a decision. In such case, leave the argument empty.
Hemisphere	Hemisphere=NA	Choose between North Hemisphere "NH" and South Hemisphere "SH" depending on the location of your system. This argument is required if you choose to plot NWT, as the age of the maximum fallout varies with the Hemisphere considered (Northern hemisphere: 1963; Southern hemisphere: 1965)
FF	FF=NA	If ^{137}Cs measurement were conducted, where do you detect the First Fallout period? The argument is a vector of two depths given in millimetres giving the top and bottom threshold for the First Fallout period in 1955. The user can run the model without giving any specification before making a decision. In such case, leave the argument empty.
inst_deposit	inst_deposit=c(0)	Upper and lower depths (in mm) of sections of abrupt accumulation that inst_deposit c() should be excised, e.g., c(100, 120,

		185, 195) for two sections of 10.0-12.0 cm and 18.5-19.5 cm depth
mass_depth	mass_depth=FALSE	Logical (TRUE/FALSE) argument, to decide whether radionuclides should be plotted against mass accumulated depth.
ignore	ignore=c()	The depth (in mm) of any sample that should be ignored from the age-depth model computation, e.g., c(55) will remove the measurement done at 55 mm (between 50 and 60 mm). The data will be plotted by default in grey on the output graph (you can change this with the inst_depositcol argument)
input_depth_mm	input_depth_mm=TRUE	Logical argument to indicate the unit of the entry depth (when user detects instantaneous deposits, Cher, NWT and FF peaks, points to ignore, or SML). By default (TRUE), entry depths in mm. If FALSE, entry depths are in g.cm-2 and are then converted in the function to allow the rest of the code to run.
Plotpdf	plotpdf=FALSE	Logical argument to indicate whether you want the output graph to be saved in pdf format to your folder.

Preview	preview=TRUE	Logical argument to indicate whether you want the output graph to be plotted. Default is TRUE, and the graph is plotted within your R session. It might be convenient to turn this argument to FALSE if errors telling you that your R window is too small continue to appear.
plotphoto	plotphoto=FALSE	Logical argument to indicate whether you want to plot the photo of the core along your age-model. If plotphoto=TRUE, you need to indicate the upper and lower limit of the photo in mm in following arguments. An additional jpg file with the photo should be included in the folder with the initial data.
Minphoto	minphoto=c()	Mandatory if plotphoto=TRUE. Lower limit of the core photo in mm, e.g., minphoto=c(0) indicates that the photo starts at 0 mm. The photo will automatically be truncated according to the minimum depth of the age model given in other arguments.
Maxphoto	maxphoto=c()	Mandatory if plotphoto=TRUE. Upper limit of the core photo in mm, e.g., maxphoto=c(320) indicates that the photo ends at 32 cm. The photo will

		automatically be truncated according to the maximum depth of the age model given in other arguments.
Pbcol	Pbcol=c("black","midnightblue"," darkgreen")	Vector of colour to plot $^{210}Pb_{ex}$ data. If length(Pbcol)>1, the different colours will be used to plot the different slopes between change(s) in sedimentation rate. Example of colour vector: Pbcol=c("black","midnightblue"," darkgreen").
inst_depositcol	inst_depositcol=grey(0.85)	The colour to plot the data points within an instantaneous deposit or ignored data. Example: inst_depositcol=grey(0.85).
modelcol	modelcol=c("black","red","darko range")	Vector of colour to plot a different model if length(model)>1. If length(modelcol)>1, the different colours will be used to plot the different changes in sedimentation rate. Example of colour vector: modelcol=c("black","red","darkor ange") to plot "CFCS", "CIC", "CRS" models in this order.
historic_d	historic_d=c()	Vector with upper and lower depths of the historical event(s), e.g., historic_d=c(120,130,220,250) will identify the event between

		both 12 and 13 cm and 22 and 25 cm on the last window of the age model.
historic_a	historic_a=c()	Vector of years of different historical events, e.g., historic_a=c(1970,1895) will add two points at 1970 and 1895 on the last window of the age model. Historical events can be older than the dated section, in which case the depth is obtained from the model if historic_d is not specified. historic_a is a vector twice as short as historic_d, as each age corresponds to an upper+lower limit in the vector 'historic_d'. If not all ages are known, put NA in the vector, e.g., historic_a=c(NA,1895)
historic_n	historic_n=c()	Vector of names of different historical events, e.g., historic_n=c("1970 flood","1895 flood"). Optional. If you plot several events and do not want to plot all the names, add an NA in the vector, e.g., historic_n=c(NA,"1895 flood") will understand that the first event does not have a name, but the second does.

suppdescriptor	suppdescriptor=FALSE	Up to two supplementary descriptor(s) to plot in an additional window. Logical argument. The decision on plotting more than one supplementary descriptor depends on the length of the vector descriptor_lab. An additional input file with these data should be included in the folder with the initial data.
descriptor_lab	descriptor_lab=c()	Label used on the axis, e.g., descriptor_lab=c("LOI", "Ca/Fe") if two supplementary descriptors are specified.
suppdescriptorcol	suppdescriptorcol=c("black","purple")	Vector of colours to plot different descriptors if length(descriptor_lab)>1. If length(descriptor_lab)>1, the different colours will be used to plot the different changes in the sedimentation rate. Example of colour vector: suppdescriptorcol=c("black","purple").
plot_Am	plot_Am=FALSE	Logical argument indicating whether or not serac should plot ^{241}Am.

plot_Cs	plot_Cs=FALSE	Logical argument indicating whether or not serac should plot ^{137}Cs.
plot_Pb	plot_Pb=TRUE	Logical argument indicating whether or not serac should plot $^{210}Pb_{ex}$.
plot_Pb_inst_deposit	plot_Pb_inst_deposit=FALSE	Logical argument indicating whether or not serac should plot $^{210}Pb_{ex}$ without instantaneous deposits. If TRUE, inst_deposit should not be a null vector.
varves	varves=FALSE	Logical argument to indicate whether varve counting results should be plotted on the last window. An additional input file with these data should be included in the folder with the initial data.
dmin	dmin=c()	Minimum depth of the age-depth model (useful if the user does not want to plot the upper part).
dmax	dmax=c()	Maximum depth of age-depth model (useful if the user does not want to plot the lower part or wants to plot data below the extent of the radionuclides data). dmax cannot be in the middle of an instantaneous deposit. For example, if there is an instantaneous deposit between 180 and 200 mm, dmax cannot be

		190 mm and will be automatically converted to 200 mm.
sedchange	sedchange=c(0)	Up to two changes in sedimentation rate, e.g., sedchange=c(175,290) indicates two changes of sedimentation rate at 17.5 and 29.0 cm.
min_yr	min_yr=1880	The minimum year limit for the age-depth model plot. The user can adjust this argument after a first computation of the model.
SML	SML=c(0)	Surface Mixed Layer: a depth in mm above which the sediment is considered to be mixed. For example, SML=30 indicates that the first 3 cm are mixed sediment: the data points are plotted but not included in the CFCS models.
stepout	stepout=1	Depth resolution for the file output in mm.
mycex	mycex=1	Graphical parameter: a multiplication factor to increase (mycex>1) or decrease (mycex<1) label sizes.
Historic_test	Historic_test=c()	Vector of years of different historical events, e.g., historic_test=c(1970). Visualisation tool for known ages. This argument will plot a vertical line in the last window. Can be

		useful when the user knows specific ages of historical events and wants to fit the model with this event.
archive_metadata	archive_metadata=FALSE	Logical argument. If TRUE, require fields regarding the measurements on the core. Allows missing information; just press 'ENTER' in your computer (leave an empty field)
save_code	save_code=TRUE	Logical argument. If TRUE (default), the code is saved in the output object. If serac is within a Shiny app, the history cannot be easily extracted, so it is convenient to be able to turn it to FALSE