Quantification of peat accumulation rates of European subarctic of Russia based on $^{210}$Pb-dating using the constant rate of the supply model (by the example of the Arkhangelsk region)

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Abstract. In this work, peat sections from various regions of the European subarctic part of Russia were studied. In peat sections from locations with different environmental conditions and time periods the isotopes of $^{210}$Pb and $^{210}$Po were determined. The determination procedure included radiochemical preparation followed by dissolution of the salts containing isotopes. The measurements were taken no earlier than 10 hours and no later than 36 hours after preparation of the counting sample. The prepared counting sample was measured on the alpha-beta radiometer. The chronology of peatlands by $^{210}$Pb was studied using a Monte Carlo simulation method according the constant rate of the supply model. The approach is implemented in the format of MS Excel spreadsheets, in which the calculated parameters are a peat core diameter, half-life of $^{210}$Pb, layer depth, dry weight, total content of $^{210}$Pb and concentration of $^{226}$Ra. The average rates of sediment accumulation of peat deposits and mass accumulation were obtained and estimated. The maximum mass accumulation rate and the sediment accumulation rate for peat profile no. 1 refer to the closely located 1979 and 1976, respectively. The maximum mass accumulation rate and the sediment accumulation rate for peat profile 2 occur in 1986. The value of the atmospheric flux $^{210}$Pb was obtained for the peat-bog ecosystems of the European subarctic part of Russia. The atmospheric flux $^{210}$Pb for the studied areas was 80-90 Bq·m$^{-2}$·year$^{-1}$ which is comparable to data for other territories of Northern Europe. The data obtained showed that the modeling method can be successfully applied to study the chronology bottom sediments in the conditions of the European subarctic part of Russia.

1. Introduction

The purpose of this study was to test the effectiveness of modeling a constant rate of supply (CRS), in particular, the Monte Carlo simulation method for determining the rates of modern peat accumulation based on the dating $^{210}$Pb sediments in peat-bog ecosystems in the the European subarctic part of Russia (using the example of the Arkhangelsk region). The method has found wide application in geochronology for radiocarbon, uranium-thorium and $^{210}$Pb dating [1-3]. To achieve this goal, the following tasks were realized: selection of peat profiles in different areas of the above region,
determination of the content of the radioactive isotope $^{210}\text{Pb}$ in the section of peat deposits; study and application of $^{210}\text{Pb}$ dating using the Monte Carlo uncertainty model for two peat profiles; determination of the rates of modern peat accumulation based on this dating.

2. Materials and methods

The selection of peat columns was carried out in the Mezen district (peat profile 1) and the Primorsky district (peat profile 2) in the Arkhangelsk region. The study areas belong to the White Sea basin. The main component of the studied peat deposits is sphagnum moss. The typical depth of peat deposits is in the range from 2.2 to 6.5 m (the average is 4.0 m) [4]. The peat columns were extracted using the PVC pipe. The cores from peat sections 1 and 2 were taken using large-diameter PVC pipes with a cross-sectional area of 625 cm$^2$. After delivery to the laboratory, the peat cores were cut into the sections from 2 to 6 cm. The cores were dried in a drying oven SNOL 24/200 at a temperature of 105 °C until air-dry. Surface vegetation was also selected and is considered as the first layer in this study. The lengths of peat profiles 1 and 2 are respectively 69 cm and 60 cm.

3. Determination of $^{210}\text{Po}$ and $^{210}\text{Pb}$ isotopes

Radiochemical preparation was carried out according to [5]. The following operations were performed sequentially: abrasion of the sample, decomposition with concentrated acid HNO$_3$ upon heating, decomposition of the sample with H$_2$O$_2$ and evaporated to wet salts. Leaching of the determined elements was carried out by treating the salts with HCl (1:2) and boiling for 1 hour. After settling, the leached material was filtered off. The watch glass, beaker and residue were washed with hot HCl (1:4). Then a second leaching of the precipitate was carried out together with the filter. During leaching, the sample was treated with a mixture of HCl (1:2) and H$_2$O$_2$ and boiled for 30 minutes. After settling, the leached material was filtered into a beaker, where the first filtrate is located. The filter cake and beaker were washed with hot HCl (1:4). HClO$_4$ was added to the combined filtrate and evaporated to thick white vapors, covered with a watch glass, and evaporation was continued until the salts began to precipitate. Then the sample was cooled, watch glasses were removed, washed with H$_2$O$_2$ distilled, and the solution was evaporated to the wet salts. The salts were dissolved at reflux after adding concentrated HCl and H$_2$O$_2$ distilled. Then the solution was diluted to 100 cm$^3$ H$_2$O$_2$ distilled and ascorbic acid was added. Isotope isolation $^{210}\text{Pb}$ and $^{210}\text{Bi}$ (in radioactive equilibrium with $^{210}\text{Pb}$) was performed from the resulting solution by chemical spontaneous precipitation of radionuclides. The deposition was carried out on a steel disk by boiling for 2 hours. The end time of electrochemical deposition was recorded in a laboratory journal. The counting sample was measured no earlier than 10 hours and no later than 36 hours after its preparation. The prepared counting sample was measured on the RKS-01A "Abelia" alpha-beta radiometer (limited liability company “NTC Amplitude”) [5].

The processing of the measurement results of the countable sample was carried out in accordance with the algorithm specified in [5] as in equation (1) using the standard office applications MS Excel. Distribution was also homogeneous enough and it had not floated to the casting surface.

The specific activity $^{210}\text{Pb}$ of the sample $A^{\text{Pb}}$ (Bq·kg$^{-1}$):

$$A^{\text{Pb}} = \frac{A_{\text{sample}}^{\text{Bi}}}{0.85 \cdot M} \cdot \phi_{\text{Bi}}$$

where $A_{\text{sample}}^{\text{Bi}}$ - activity $^{210}\text{Bi}$ the countable sample (Bq); $\phi_{\text{Bi}}$ - coefficient taking into account the decay of $^{210}\text{Bi}$ for the time of electrochemical deposition before measurement; 0.85 – constant coefficient (radiochemical yield $^{210}\text{Bi}$); M – weighed sample taken for analysis (kg) [5].

4. CRS modeling. Monte Carlo simulation method

In this study, the calculation of the uncertainty of $^{210}\text{Pb}$ dating and the accumulation rates of peatlands by modeling use a Monte Carlo simulation method according the CRS model [6, 7]. The method is based on the model of a constant flux $^{210}\text{Pb}$. $^{210}\text{Pb}$ dating models including basics, nomenclature and
formulation are described by a number of authors [8-10]. The model used is considered in detail in [6].

The Monte Carlo modeling acts as an alternative to the quadratic distribution of uncertainties. The data is organized in a spreadsheet that allows the iterative calculation. The calculated parameters are: core diameter, half-life of \(^{210}\)Pb, layer depth, dry weight of the layer, total content of \(^{210}\)Pb and concentration of \(^{226}\)Ra. The number of iterations was 10000 [6, 7]. The methodology was applied to 2 peat cores from locations with different environmental conditions and time periods.

5. Results

Following the radiochemical method mentioned above, \(^{210}\)Pb in the dry samples was determined after its radiochemical separation and measured using the \(\beta\)-spectrometry [5]. The study of \(^{210}\)Pb in the peat profile 1 was carried out to a depth of 45 cm, which was associated with the absence of excess atmospheric \(^{210}\)Pb in the underlying horizons. The total activity of \(^{210}\)Pb varied to 185.2 ± 38.6 Bq·kg\(^{-1}\) in the first section of the core from 16.07 ± 7 Bq·kg\(^{-1}\) in the lower section. The age of the lower main layer was 131.3 ± 10.3 years. The expected estimated simulation time taken to form each section varied to 6.9 years in the 1-6 cm section from 21.9 years in the 43-45 cm section with an average of 6.6 years.

The linear rate of accumulation of peat deposits for the peat profile 1 averaged 0.437 cm·year\(^{-1}\). The value of the uncertainties in the rate of mass accumulation decreased to 0.0447 ± 0.0308 g·cm\(^{2}\)·year\(^{-1}\) in the upper layer from 0.0151 ± 0.0044 g·cm\(^{2}\)·year\(^{-1}\) in the lower layer (43-45 cm) (figure 1).

Figure 1. Mass accumulation rate (in red) and the sediment accumulation rate (in blue) in the first peat column.

We should note that the average was 0.308 ± 0.112 g·cm\(^{-2}\)·year\(^{-1}\), and the noted maximum of 0.1266 ± 0.0977 g·cm\(^{-2}\)·year\(^{-1}\) falls on 1979. The uncertainty values for the mass accumulation rate for peat profile 1 are low, mainly due to the fact that \(^{226}\)Ra was not considered as a source of uncertainty in the calculation. The obtained values of the activity of \(^{210}\)Pb in the lower horizons of the core indicate radioactive equilibrium with \(^{226}\)Ra. The uncertainty values of the mass accumulation rate (figure 1) decreased to 0.145 ± 0.038 cm·year\(^{-1}\) from 0.095 ± 0.027 cm·year\(^{-1}\). The noted maximum of 1.047 ± 0.312 cm·year\(^{-1}\) falls to year 1976.

The study of \(^{210}\)Pb in peat profile 2 was carried out to a depth 48 cm, which was associated with the absence of excess atmospheric \(^{210}\)Pb in the underlying horizons. The total activity of \(^{210}\)Pb varied to 281.9 ± 45.7 Bq·kg\(^{-1}\) in the first section of the core from 40.2 ± 6.5 Bq·kg\(^{-1}\) in the lower section. The age of the lower main layer was 131.8 ± 5.1 year. The expected estimated simulation time taken to
form each section varied peat profile 2 ranged to 4.1 year in the 1-2 cm section from 22.0 years in the 44-46 cm section with an average of 5.7 years.

![Figure 2. Mass accumulation rate (in red) and the sediment accumulation rate (in blue) in the second peat column.](image)

The value of the uncertainties in mass accumulation rate of peat profile 2 (figure 2) decreased to 0.0274 ± 0.0168 g·cm⁻²·year⁻¹ in the upper layer from 0.0048 ± 0.0120 g·cm⁻²·year⁻¹ in the lower layer (44-46 cm). The average was 0.0307 ± 0.0146 g·cm⁻²·year⁻¹, and the maximum recorded at 0.0650 ± 0.0217 g·cm⁻²·year⁻¹ falls to 1986.

The uncertainty values for the sediment accumulation rate for peat profile 2 decreased to 0.380 ± 0.116 cm·year⁻¹ from 0.094 ± 0.039 cm·year⁻¹. The average was 0.4412 ± 0.159 cm·year⁻¹, and the maximum noted 1.0913 ± 0.0223 g·cm⁻²·year⁻¹ falls to 1986.

The age of the peat cores by ²¹⁰Pb dating was calculated for each selected range of the peat core depths within the total core depth. The linear sediment accumulation rate, obtained using ²¹⁰Pb, varied to 0.095 ± 0.027 cm·year⁻¹ from 1.047 ± 0.312 cm·year⁻¹ for the peat profile 1 and varied to 0.094 ± 0.239 cm·year⁻¹ from 1.091 ± 0.348 cm·year⁻¹ for the peat profile 2. High values were calculated for the section 21-23 cm in 1976 for the core 1 and for the section 14-16 cm in 1986 for the peat core 2. The average rates of peat accumulation in the peat profiles 1 and 2 are very similar, which is probably due to similar environmental factors that determine approximately the same linear sediment accumulation rates of peat accumulation.

The atmospheric flux ²¹⁰Pb for surface peat profile 1 was 91.67 ± 0.22 Bq·m⁻²·year⁻¹, and for profile 2 it was 80.45 ± 1.08 Bq·m⁻²·year⁻¹. For the northern latitudes (30°–60°) the average flux of ²¹⁰Pb is 117 Bq·m⁻²·year⁻¹ [11]. For the Nordic countries Finland, Sweden and Estonia, the calculated lead-210 flux is in the range of 50-92 Bq·m⁻²·year⁻¹ [11-13].

As can be seen from the data obtained, the atmospheric flux ²¹⁰Pb, calculated for the Arkhangelsk region, is comparable with the data for other territories of Northern Europe.

6. Conclusion
The data obtained showed that the modeling method used in this work can be successfully applied to study the chronology of other young sedimentary deposits, in particular, bottom sediments in the conditions of the European subarctic of Russia.
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References
[1] Binford M W 1990 *J. Paleolimnol.* 3 253–68
[2] Hellstrom J 2006 *Quat. Geochronol.* 1(4) 289–95
[3] Ramsey C B, van der Plicht J, Weninger B 2001 *Radiocarbon* 43 (2A) 381–89
[4] Antipin V K, Elina G A, Tokarev P N, Brazovskaya T I 1996 *Botanicheskij Zhurnal* 81(I) 21–38
[5] Bahur A E, Manuilova L I, Zueva D M, Ovseyannikova T M, Trukhina T P 2013 *The method for measuring the specific activity of polonium-210 (210Po) and lead-210 (210Pb) in samples of soils, bottom sediments, rocks and building materials based on them using an alpha-beta-radiometric method with radiochemical preparation* (Moscow: VIMS) p 17
[6] Sanchez-Cabeza J A, Ruiz-Fernandez A C, Ontiveros-Cuadras J F, Peres Bernal L H, Olid C 2014 *Quat. Geochronol.* 23 80–93
[7] Sanchez-Cabeza J A, Ruiz-Fernandez A C 2012 *Geochim. Cosmochim. Acta* 82 183–200
[8] Appleby P G, Oldfield F 1978 *Catena* 5 1–8
[9] Krishnaswamy S, Lal D, Martin J, Meybeck M 1971 *Earth Planet. Sci. Lett.* 11 407–14
[10] Robbins J A 1978 Geochemical and geophysical applications of radioactive lead isotopes, in: *Biochemistry of Lead* (Amsterdam: Elsevier) pp 85–393
[11] Preiss N, Mélières M-A, Pourchet M 1996 *J. Geophys. Res.* 101(D22) 28847-862
[12] Realo K, Realo E 2001 210Pb in Estonian soil *Proc. IRPA Regional Congress on Radiation Protection in Central Europe* (B Obelic, M Ranogajec-Komor et al, eds) (Dubrovnik: Croatian Radiation Protection Association) pp 1–6
[13] Paatero J, Jaakkola T, Kulmala S 1998 *J. Environ. Radioact.* 38 223–47