Intercomparison of radiocarbon bomb pulse and ^{210}Pb age models. A study in a peat bog core from North Poland.

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Abstract

Radiocarbon and ^{210}Pb were measured on the uppermost 40 cm of a Wardenaar peat core retrieved from a Baltic raised bog at Słowińskie Błota (Pomerania, North Poland). This site is the subject of ongoing multiproxy studies covering the last 1300 years. Radiocarbon age model was constructed on the basis of 14 AMS dates obtained on selected *Sphagnum spp.* fragments, with use of *P_Sequence* tool. We present here a comparison of this model with the age model obtained using CRS model classically applied to ^{210}Pb measurements.

1. Site and objectives

Słowińskie Błota peat bog is located 8 km to the south-east of Darłowo city, and 10 km away from the Baltic Sea (Fig. 1A). It is one of the best-preserved Baltic raised peat bogs in Poland, and at present it is exclusively ombrotrophic. The peat bog is of elliptical shape, with semi-axis of 1.8 and 0.9 km long, and covers an area of 1.2 km^2. The actual vegetation is composed of several species of *Sphagnum*, and in the outer parts blueberry, heather and white birch are present (Fig. 1B).

The central part of the peat bog has been cored in 2006 using a Wardenaar sampler [2] in the framework of a project aimed on high resolution multiproxy investigations of past environmental conditions, performed on two 1-metre-long profiles, reaching ca. 700AD. These studies include plant macrofossils, pollen, testate amoebae [3], stable carbon isotopes, elemental geochemistry and lead isotopes [4,5].

^{14}C and ^{210}Pb dating methods were applied in order to obtain timescale for the studies mentioned above. The present work focuses on the last 150 years and is aiming to compare the age-depth models constructed independently on the basis of ^{14}C and ^{210}Pb dating methods for this period. The main purpose of this study is to look for the best-constrained and precise age-depth model for the period since Industrial Revolution.

2. Methods

2.1. ^{210}Pb dating

One-centimeter thick samples for ^{210}Pb dating were prepared by sequential HNO_3-H_2O_2-HCl digestion and polonium was deposited on silver discs. Alpha activity was measured using a Canberra model 7401 spectrometer equipped with a surface-barrier Si semiconductor detector. The nearly constant activity of ^{210}Pb (ca. 10 Bq/kg), which was detected below 34 cm depth, was assumed to represent the supported ^{210}Pb. Calculated activities of unsupported

^{210}Pb and Constant Rate of Supply (CRS) [6] model allowed the construction of an age-depth relationship [4].

2.1. ^{14}C dating

Macrofossils were carefully selected from fourteen 1-cm peat slices under a binocular microscope. In case of insufficiency of *Sphagnum* fragments, other aboveground plants or large charcoal fragments were picked up. Great care has been taken to remove roots and rootlets in order to avoid carbon contamination from overlying layers. The composition of samples is presented in Tab.1, and basically reflects well the plant macrofossil composition reported in [4]. In the zone of high *Sphagnum* content, which is up to the depth 15cm, the samples are composed by pure *Sphagnum* stems or branches, whereas in the lower part, where the abundance of *Erica* and *Calluna* remains increased, the samples for radiocarbon dating contain also those species.

All samples were chemically cleaned using an acid-alkali-acid treatment, and subsequently combusted, according to the protocol described in [7]. The CO_2 was graphitized during the reaction with H_2 at 600°C, on Fe catalyst. Measurements were performed with use of NEC 0.5MV Pelletron spectrometer in Poznan Radiocarbon Laboratory, Poland [8].

2.3. Calibration of ^{14}C results

Calibration of radiocarbon dates was undertaken using the Intcal04 calibration curve [9] and NH1curve [10]. In order to reach the year of collection (2006) the NH1 curve had to be extrapolated to year 2006, which was done with use of exponential function. OxCal 4.0 software was used [11], and *a priori* information about depths was introduced in a *P_Sequence* model [12], which is based on a Bayesian theorem. The discrepancy within the sequence appeared when all the radiocarbon dated levels were considered. This problem could be solved only if one date was considered to be an outlier and excluded from the model. In view of probability distributions plotted versus depth (Fig.2), it seems that one of the samples at depths 21-22 or 26-27 should be removed. Taking into consideration the composition of the samples (Tab. 1), it was decided to reject the lower one (GdA-1096, depth 26-27 cm), as it included mixed material, in contrary to pure *Sphagnum* branches selected form the level 21-22 cm.

3. Discussion

Both ^{210}Pb and ^{14}C dating methods have specific assumptions and limitations, which influence the results of modelling. The age-depth relationship calculated using the CRS model is limited in resolution by the sample thickness (in our case 1cm). Moreover, every age is calculated on the basis of the summed activity of underlying samples and the total core ^{210}Pb inventory. Therefore the ages of two contiguous samples are interdependent. Consequently, the result of a single dating is described by a Gaussian distribution of an age for a given depth, with a standard deviation of several years. The midpoint of each Gaussian distribution fall on an exponential-like curve. On the contrary, the results of ^{14}C dating are independent from each other. The most problematic issue here is the presence of large wiggles in the calibration curve during the 19th century, which leads to multi-modal probability distributions covering wide time intervals. The incorporation of sample depths in Bayesian modelling results in a meaningful reduction of the uncertainties. However, in order to obtain a statistically relevant agreement within the sequence, it also requires the removal of one date (GdA-1096, depth 26-27 cm).

3.1. Comparison of models

Figure 2 presents an attempt to compare the ^{14}C *P_Sequence* age-depth model with the CRS ^{210}Pb model. In a first attempt, the most probable approach in the construction of an age-depth model is to consider the hypothetical curves drawn through the midpoints of the probability distributions obtained after modelling (dark-grey-colored on Fig. 2). For the depth until ca. 14 cm, both models are in very good agreement. In the deeper interval, a minor shift (several years, up to ca. 16 years between midpoints for the depth 17.5cm) of ^{14}C model towards older ages is observed. This shift seems however negligible compared to the discrepancy for the pre-bomb period (depth range 31-35cm), where the difference between midpoints reaches even 100 years towards older ^{14}C dates.

It should be noticed, that both models give similar sedimentation rates averaged for the whole sequence, which are 0.125 and 0.121 cm/yr for the ^{210}Pb and ^{14}C model, respectively. As a consequence, each centimeter grew between *ca*. 8.0 (^{210}Pb) and 8.3 (^{14}C) years. For the interval above 22.5 cm the accumulation rates are 0.625 (^{210}Pb) and 0.526 cm/yr (^{14}C) (1.6 and 1.9 yrs/cm) and for the interval below 22.5cm they are 0.0521 (^{210}Pb) and 0.0515 (^{14}C) cm/yr (19.2 and 19.4 yr/cm). Taking into consideration the density reported in [4] the mean accumulation rate in grams per square centimeter per year can be calculated for the abovementioned periods, which is ca. 12g/(cm^2*year) for the upper part and ca. 4 g/(cm^2*year) for the lower section.

3.2. Natural considerations

The large difference observed for the lower samples may have various reasons. Both ^{14}C and ^{210}Pb signals are integrated over a considerable period of time. Moreover, they originate from different sources. ^{210}Pb is bound to aerosols and trapped by peat, while ^{14}C is bound from atmospheric CO_2 by photosynthesis. Hence, the ^{14}C date gives the time of death of a plant whereas ^{210}Pb gives the time span during which the aerosol has been buried, allowing subsequent ^{210}Pb decay. It has been demonstrated in several studies that ^{210}Pb is not subject to post-depositional mobilisation in ombrotrophic peat (e.g. [13, 14]). On the other hand, the CO_2 can be released during the decomposition of organic matter under oxic conditions and emanate to the upper sections. The age of this CO_2 is greater than contemporary growing peat, thus it shifts the age of the living peat towards older time [15]. However, in the case of Słowińskie Błota the emanation of CO_2 seems unlikely due to ombrotrophic character of the bog (*i.e.* acidic and anoxic). Moreover, if ever occurring in our profile, this phenomenon should be much more pronounced for the post-bomb part of the data, which is not the case here.

3.3. Statistical considerations

Having assessed the natural causes of the discrepancies between both models to be unlikely, care should be taken to the way the models are built. When the unmodelled probability distributions are taken into consideration, the inconsistency of both models may not be significant. Narrower ranges of probability distributions were produced by statistical calculations, which were performed in such way that there is no information about ^{210}Pb dating available. Above-mentioned wiggles in the ^{14}C calibration curve are responsible for wide ranges of probability distributions, *i.e.* up to 300 years. The *P_Sequence* model is only one way of dealing with such a set of dates, a common one at present [16,17,18]. The other approach could be the wiggle-matching of the sequence to the ^{14}C calibration curve [19]. However, the present dataset needs to be improved in resolution to allow such calibration. Other age-modelling tools, which could be applied to present set of dating include non-linear regression [20] or application of cubic splines with curvature calculations [21].

The coupled ^{210}Pb-^{14}C model was applied for other studies for the complete 1-m core presented here The upper part of complete model was based on ^{210}Pb data, while calibrated

^{14}C ages were used from 34 cm downwards. The results plotted on this timescale are in good agreement with historical data and correlation with other palaeoenvironmental records [4,5].

4. Conclusions

The present study highlight some important issues connected with radiocarbon dating of peat sequences. Commonly known problems caused by wiggles in calibration curve for the period covering the bottom part of Słowińskie Błota peat core can almost certainly be solved by the ^{14}C dating of more samples from thinner slices. This study shows also, that the post-bomb calibration curve needs to be extended to the present time. It also highlights the great potential of Bayesian analysis applied in radiocarbon calibration, which, however, should be applied with caution. The high suitability of coupled ^{210}Pb-^{14}C dating applied to dating of ombrotrophic peat bogs was also confirmed.

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Figure captions

Fig. 1. (A) Location of Słowińskie Błota peat bog. (B) Simplified peatland preservation indices based on stereoscopic aerial photographs [1]: 1/ *Sphagnum* dominated vegetation; 2/ Swamp vegetation with *Sphagnum* spp., *Vaccinium uliginosum* shrubs and small pine trees; 3/ Various forests (pines, alder an other shrubs) on mineral or peaty soils; 4/ Community of *Calluna vulgaris* on dry peat; 5/ Recent anthropogenic vegetation (pastures, planted trees, etc.); 6/ Drainage ditches.

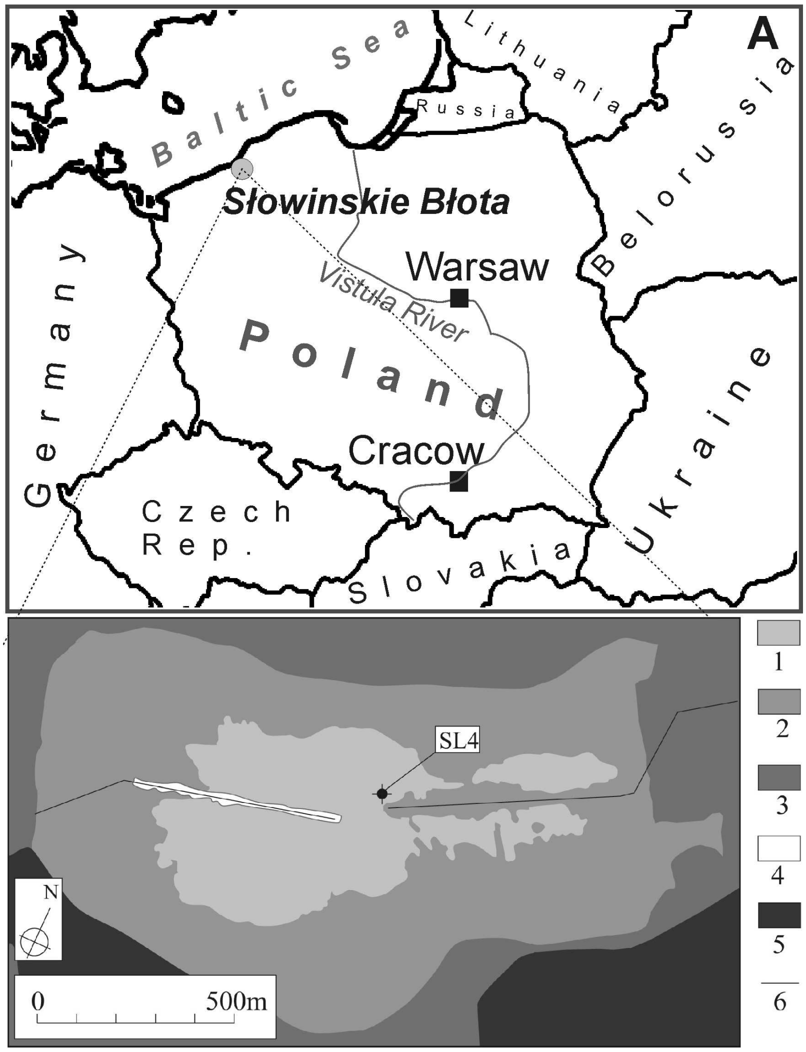
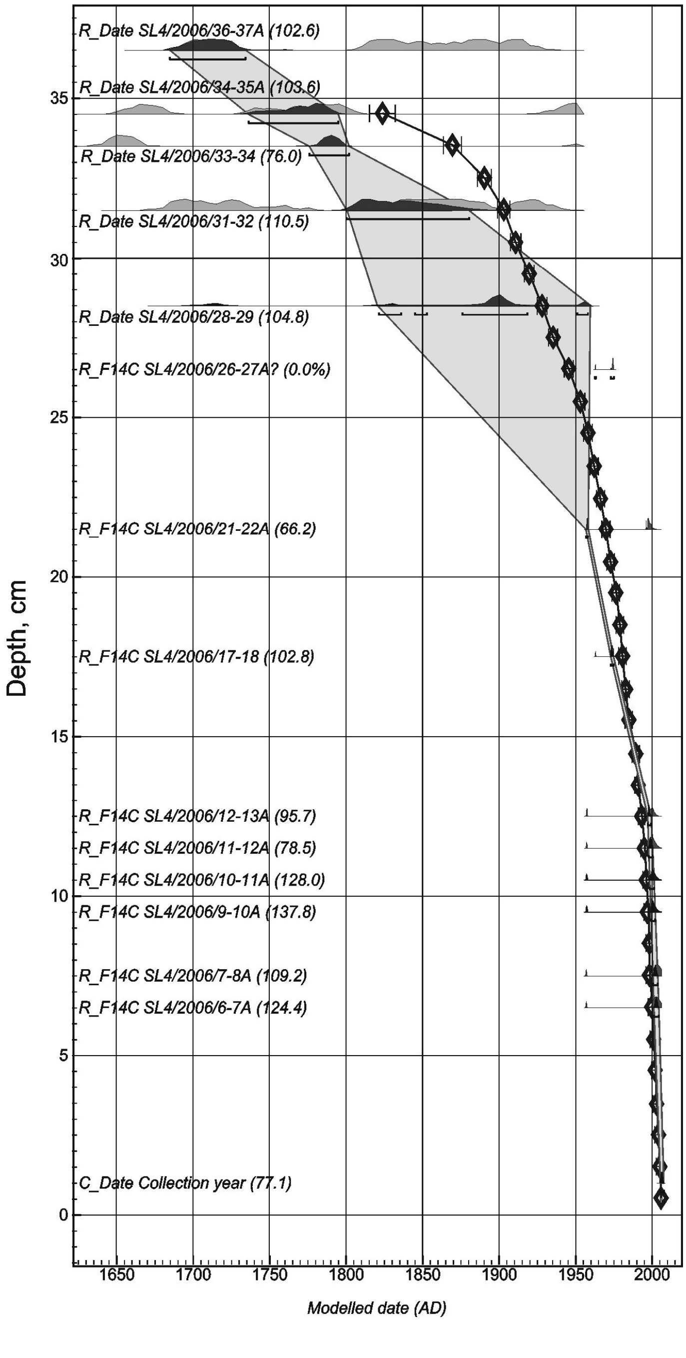


Fig. 2. Comparison of probability distributions of calendar ages obtained for ^{14}C results (light grey for unmodelled probability distributions, dark grey for modelled ones) with ^{210}Pb CRS model (black diamonds), plotted on the depth scale. Calibration performed with *P_Sequence* model (k=1/cm). The date for depth 26.5cm was excluded from age model, which results in overall agreement A=95%.



Lab No	Sample depth (cm)	Sample composition	^{14}C age/ Fraction Modern	±	95.4% age interval yr cal AD		Midpoint yr cal AD	±	^{210}Pb age yr cal AD	±
GdA-1112	6.5 ± 0.5	*Sphagnum spp. stems*	1.0689	0.0032	2007.5	2005.5	2006.5	1	1999.7	2.2
GdA-1113	7.5 ± 0.5	*Sphagnum spp. stems*	1.0661	0.0033	2004.3	2001.2	2002.75	1.59	1998.7	2.2
GdA-1115	9.5 ± 0.5	*Sphagnum spp. stems*	1.0855	0.0034	2003.6	2000.5	2002.08	1.54	1996.9	2.2
GdA-1116	10.5 ± 0.5	*Sphagnum spp. branches*	1.0854	0.0029	2002.0	1999.2	2000.61	1.43	1995.8	2.2
GdA-1117	11.5 ± 0.5	*Sphagnum spp. branches*	1.0833	0.0032	2001.2	1998.4	1999.77	1.41	1994.5	2.2
GdA-1118	12.5 ± 0.5	*Sphagnum spp. branches*	1.0905	0.0034	2000.3	1997.7	1999.01	1.29	1992.7	2.2
GdA-1314	17.5 ± 0.5	*Sphagnum spp. branches and capitulum, Calluna vulgaris stems, Erica tetralix inflorescence*	1.4319	0.0032	1999.3	1997.1	1998.21	1.11	1980.3	2.4
GdA-1087	21.5 ± 0.5	*Sphagnum spp. branches*	1.0987	0.0033	1974.7	1972.9	1973.82	0.92	1969.6	2.6
GdA-1096*	26.5 ± 0.5	*Sphagnum spp. stems, Erica tetralix inflorescence, betula catkin, unidentified seeds*	1.4219*	0.0040	1957.7	1957.2	1957.48	0.24	1945.8	2.8
GdA-1316	28.5 ± 0.5	*Calluna vulgaris branches, Erica tetralix inflorescence, unidentified seed*	40	25	1958	1822	1890	68	1928.2	3.2
GdA-1317	31.5 ± 0.5	*Sphagnum spp. stems, Calluna vulgaris branches, unidentified seeds*	120	30	1881	1801	1841	40	1902.2	3.8
GdA-1318	33.5 ± 0.5	*Shagnum spp. capitulum, Erica tetralix inflorescence, Calluna vulgaris branches, Andromeda polyfolia leave*	250	30	1802	1776	1789	13	1869.6	5.7
GdA-1097	34.5 ± 0.5	*Sphagnum spp. branches and capitulum. Erica tetralix inflorescence*	200	30	1796	1736	1766	30	1823.7	8.1
GdA-1088	36.5 ± 0.5	*Sphagnum spp. branches and capitulum, Calluna vulgaris branches, Erica tetralix inflorescence, seeds*	95	25	1735	1685	1710	25		

Tab. 1. Samples used for AMS radiocarbon dating, along with relevant information (composition, depth, calibrated age). The corresponding ^{210}Pb ages reported in (3) are also listed here for comparison. The date for depth 26.5 (marked with asterisk) was excluded from age modelling.