Comparison of lake sediments age-depth model based on the high resolution ^{14}C datings with varve chronology - Lake Soppensee case

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Fig. 1. Soppensee - lake located ca. 17 km NE of Lucerne in the Alpine foreland in Central Switzerland. It is an eutrophic lake with a biochemically controlled sedimentation. The surface area is 0.227 km². Coordinates: 47° 5′25″N, 8° 4′51″E.

Fig. 2. Laminations provide high resolution climate records.

Two chronological Holocene records were obtained for laminated sediments of the Soppensee Lake (Switzerland) high resolution radiocarbon chronology and varve chronology (Hajdas et al. 1993). The new statistical tools for age-depth model construction, which are available in OxCal (Bronk Ramsey, 2008) allow to precise the results of radiocarbon dating and to create improved deposition model. The aim of our work was to compare these two records.

Floating varve chronology constructed in 1993 (Hajdas et al.) on the basis of several cores taken from the Soppensee Lake was fitted to the first international calibration curve (Stuiver et al., 1986) in order to obtain absolute chronology. Here we used OxCal *D_Sequence* wiggle-matching procedure (Bronk Ramsey et al. 2001) to fit floating varve chronology to IntCal04 (Reimer et al. 2004). As a result the anchor of the chronology was shifted by 64 years towards the older ages.

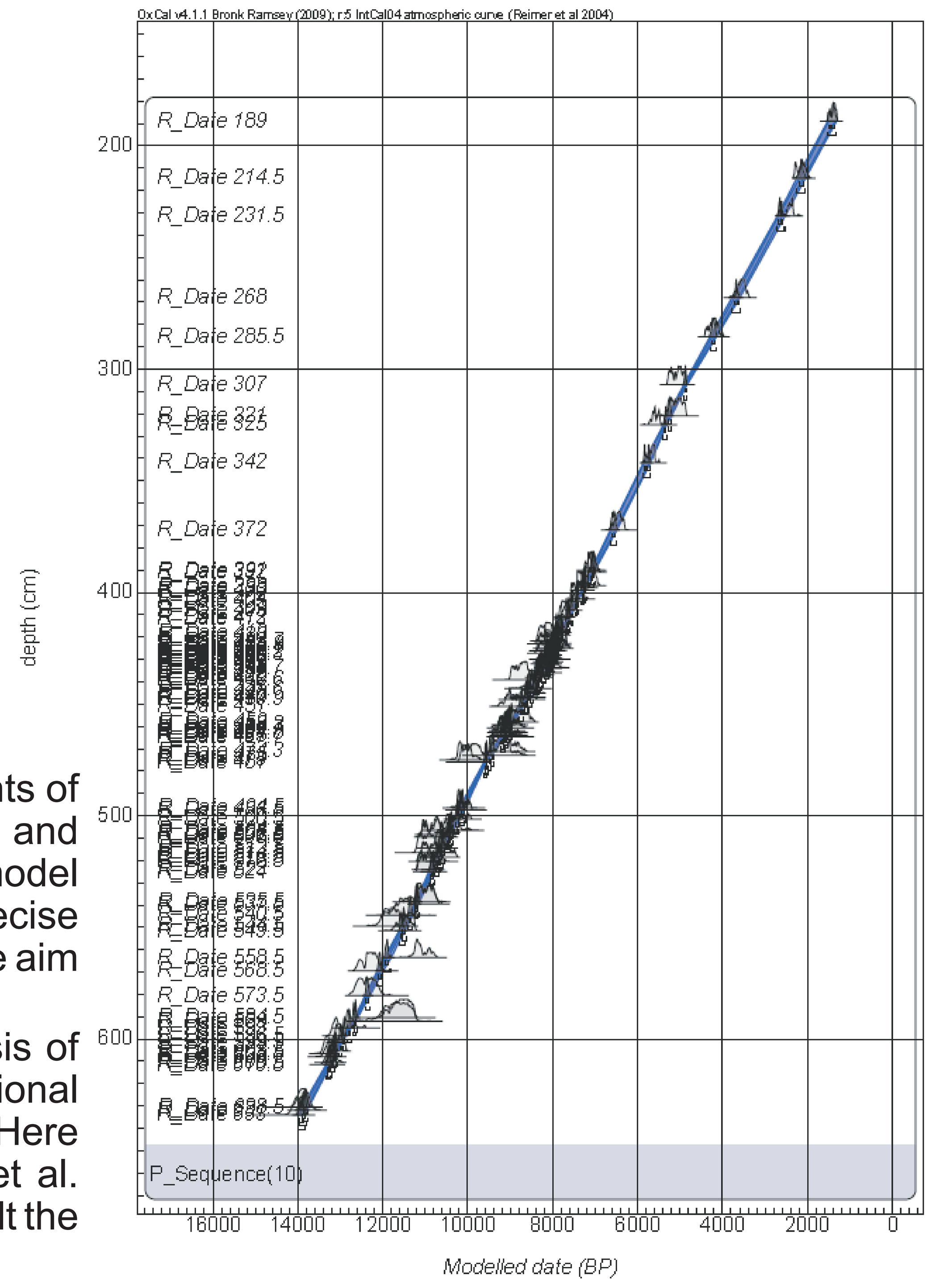

Fig. 3. *P_Sequence* age-depth model constructed using 93 radiocarbon dates.

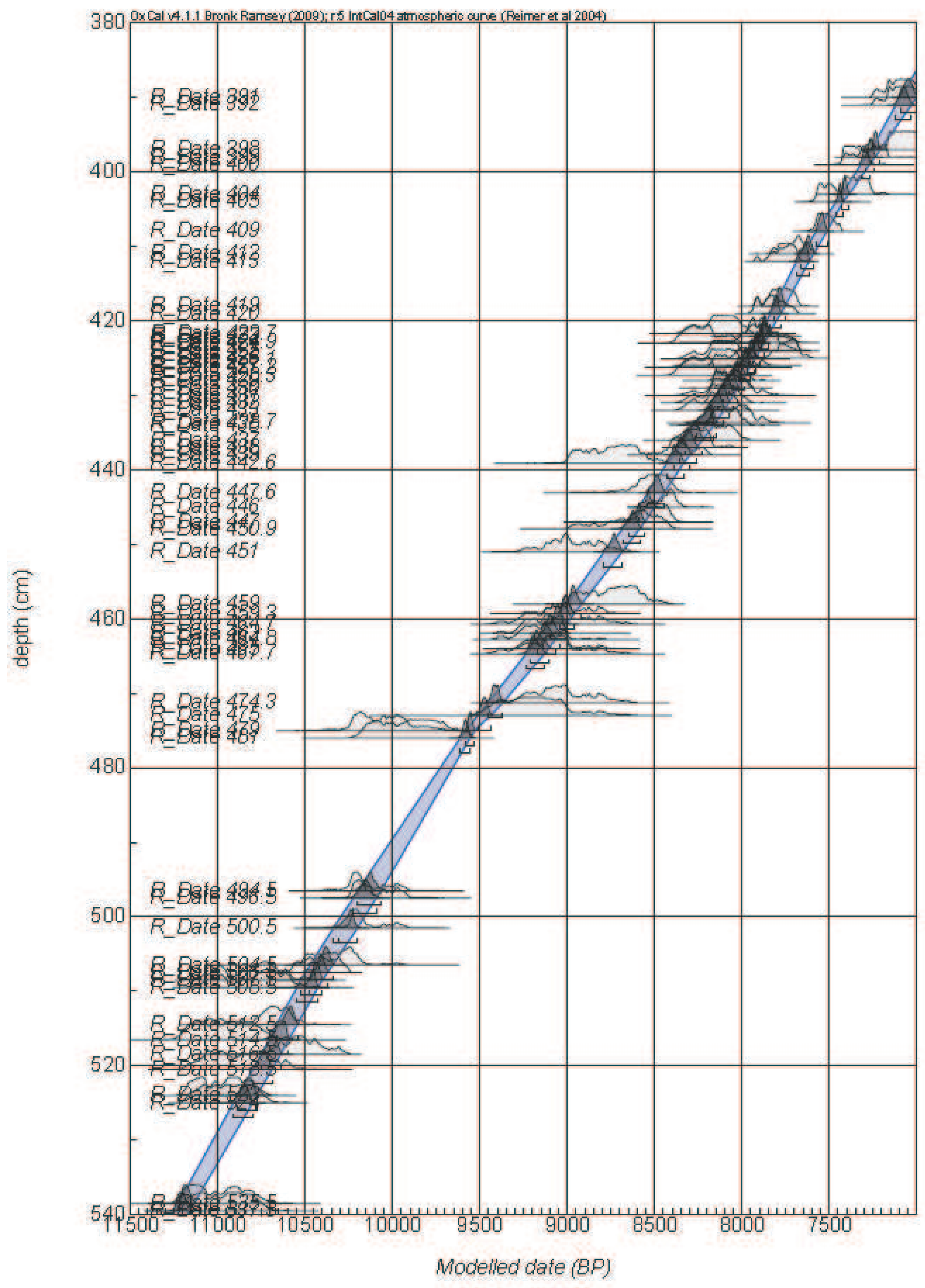

Fig. 4. Fragment of *P_Sequence* age-depth model for distinctly laminated part of Soppensee core.

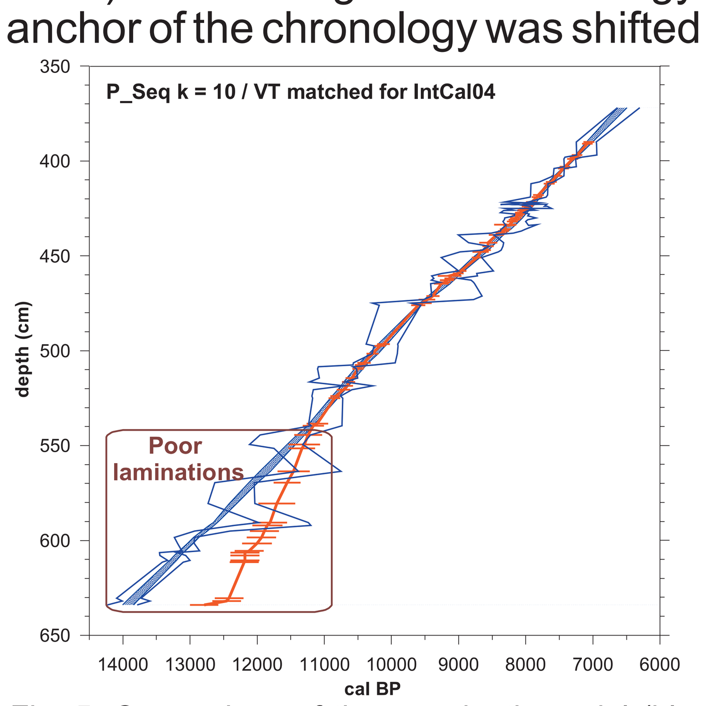

Fig. 5. Comparison of the age-depth model (blue lines - 95% confidence intervals of the prior likelihood distributions, blue strip - 95% confidence intervals of modeled likelihood distributions) and the varve chronology (orange line).

Our age-depth model was constructed using 65 radiocarbon dates form distinctly laminated part of Soppensee core, 18 dates from poor laminated and 10 dates from upper, unlaminated part. The model was developed with the aid of OxCal *P_Sequence* function (see Figures 3 and 4). We decided not to remove these dates, which were the outliers and had a small value of an agreement index between a prior and posterior (modeled) likelihood distribution. However we have tested that the removal of these dates with small values of agreement index does not changed the results (final deposition model) significantly. Figure 5 presents the final age-depth model (blue strip 95% confidence intervals of the posterior likelihood distributions, *P_Sequce* parameter k=10 cm^{-1}) and varve chronology (orange line). It is clearly visible that for the distinctly laminated part of the core (depth 380-540 cm) both records are in a very good agreement.

We repeated construction of the *P_Sequence* age-depth model assuming three different values of the k parameter - 0.5, 3 and 10 cm^{-1} and compared the results of these three models with the varve chronology. The comparison was done by calculation of agreement index between modeled calibrated ^{14}C age probability distribution and varve age distribution for each pair of radiocarbon and varve ages. The method of agreement index calculation was the same as the one used in OxCal to compare prior and posterior distributions. Finally, the overall agreement index of analyzed section of chronology was calculated. We focused on the section with depth 380-540 cm, where good lamination was observed. The results are presented in Figure 6. The best agreement between varve chronology and OxCal *P_Sequence* age-depth model is observed for k=10 (cm^{-1}).

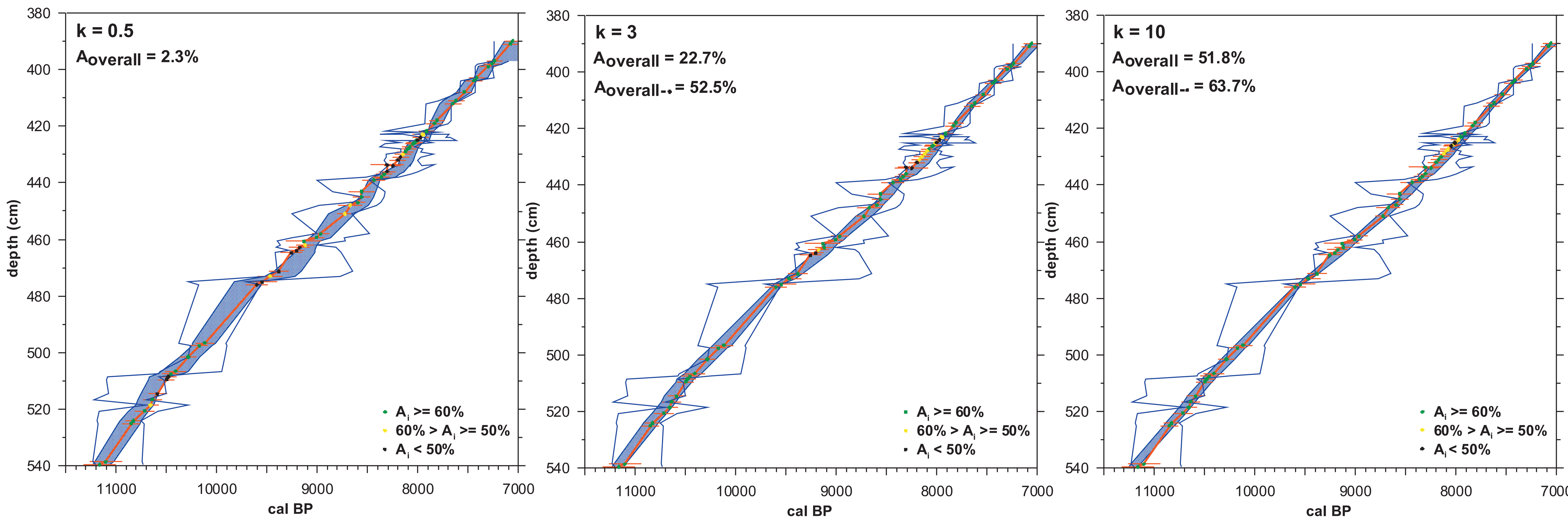

Fig. 6. Comparison of the age-depth model with the varve chronology for different values of the parameter k.
Blue lines mark 95% confidence intervals of the prior likelihood distributions, blue strip - 95% confidence intervals of modeled (posterior) likelihood distributions. Varve chronology is presented by orange line, with 2σ errors marked by orange dashes. Different colours of points indicate different values of individual agreement indices (see legend on the graphs).

Agreement indices

The agreement between the results of age-depth model, which was constructed using OxCal *PSequnce* and the varve chronology, was tested by agreement indices defined similarly as the indices calculated in OxCal (Bronk Ramsey, 2001). For individual radiocarbon dated varve level the modeled (posterior) likelihood distribution $p_m(t)$ was compared with the likelihood distribution of varve time $p_v(t)$. In order to do that the individual agreement index A was calculated as follows:

$$A = \frac{\int p_v(t)\cdot p_m(t)}{\int p_v(t)\cdot p_v(t)}$$

The likelihood distribution of varve time $p_v(t)$ was assumed to be Gaussian distribution.

To check the agreement of the group of n pairs the modeled likelihood distribution and the varve time likelihood distribution for given time (depth) interval the overall agreement index $A_{overall}$ was determined. It is defined in the following way:

$$A_{overall} = \left\{\prod_{i=1}^{n} A_i\right\}^{1/\sqrt{n}}$$

were A_i is the individual agreement index calculated for pair number i.
Both, the overall agreement index and the individual agreement index are expressed in per cent.

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CONCLUSIONS:

- As a result of wiggle-matching to IntCal04, the anchor of the floating Soppensee varve chronology (Hajdas et al. 1993) was shifted by 64 years towards older ages.
- The corrected chronology fits well to OxCal *P_Sequence* age-depth model for the whole interval of distinct lamination (depth 390-540 cm, absolute age 7060 BP 11160 BP). This shows a great potential of the age-depth construction using the statistical tool and high resolution radiocarbon dating. On the other hand precision and accuracy of varve chronology of Soppensee sediments is confirmed.
- The agreement between varve chronology and OxCal *P_Sequence* age-depth model depends on the assumed value of k parameter. The best agreement is observed for k=10 (cm^{-1}). This value reflects a scale of a thickness of the varves, which are less than 1 mm thick.
- In our opinion this analysis of the dependence of the agreement between varve chronology and OxCal *P_Sequence* age-depth model on the k parameter may help to estimate a value of this parameter in other lake sediments.
- A greater value of the k parameter shows that the age-depth model is close (or closer) to linear and fluctuations of deposition process were small. This indicates that conditions of the deposition in the Lake Soppensee were rather stable in the time period 7060 BP 11160 BP. In contrast, the beginning of the part of core with poor laminations (depth 540 cm, absolute age 11160 BP) was deposited during very unstable environmental conditions.

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