IS IT POSSIBLE TO FIND A GOOD POINT ESTIMATE OF CALIBRATED RADIOCARBON DATE ?

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PHYSICS IN EARTH SCIENCES
ENVIRONMENT AND ARCHAEOLOGY

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Procedure of probabilistic calibration of radiocarbon dates has been worked out twenty years ago and it is now widely known by community of radiocarbon dates users, but the interpretation of the results of calibration is still an object of discussion. The result of probabilistic calibration of radiocarbon date is given in form of probability distribution, therefore a giving of 68% and 95% confidence interval has became an international standard of reporting radiocarbon dates. However quite a lot of users of radiocarbon dates still tries to present the results of calibration as a single point e.g. centre of 95% confidence interval. This manner of presentation is especially often applied, because of its convenience, to construction the age-depth models.

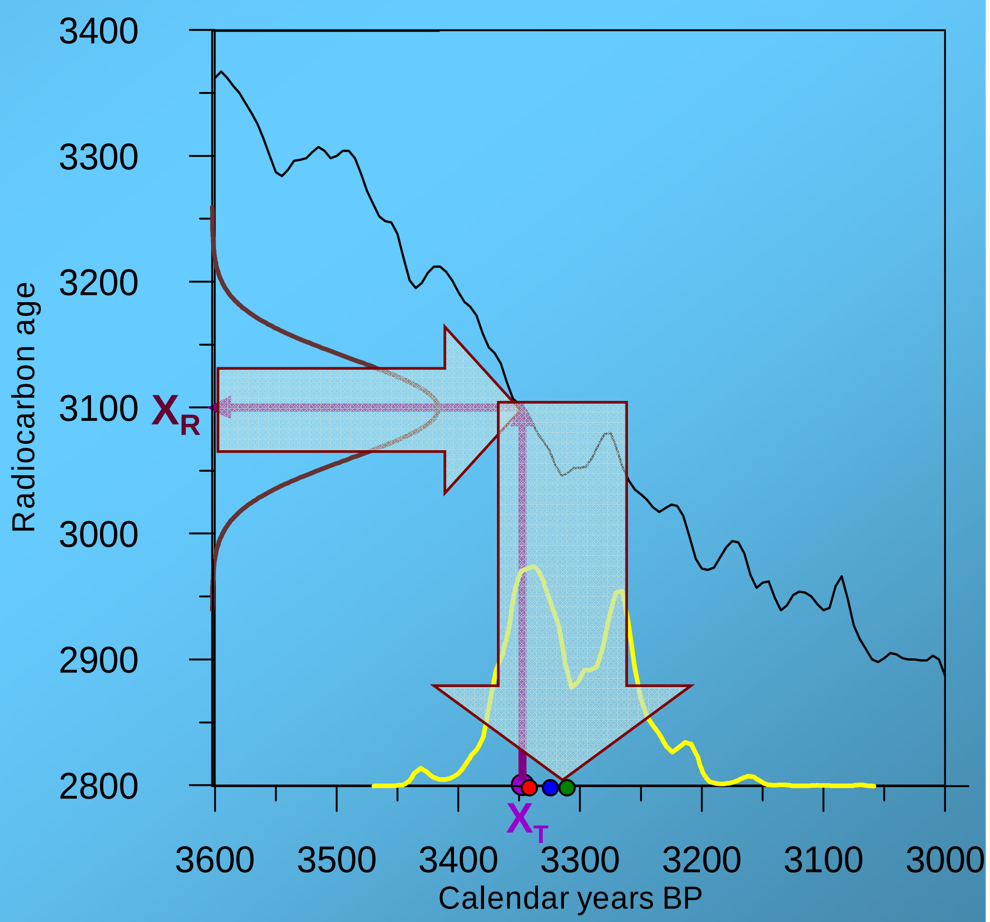
This presentation shows an attempt to test if it is possible to find a good point estimate of calibrated radiocarbon date. The idea of the test is to compare, using computer simulation, the true value of calendar age of sample with the age calculated based on probabilistic calibration of radiocarbon date and assumed method of finding the point estimate.

The idea of simulation

In order to find answer we try to calculate a few statistical parameters of distribution of calibrated radiocarbon date and to check which of them estimates true calendar age in the best way.

The idea of simulation is as follows:

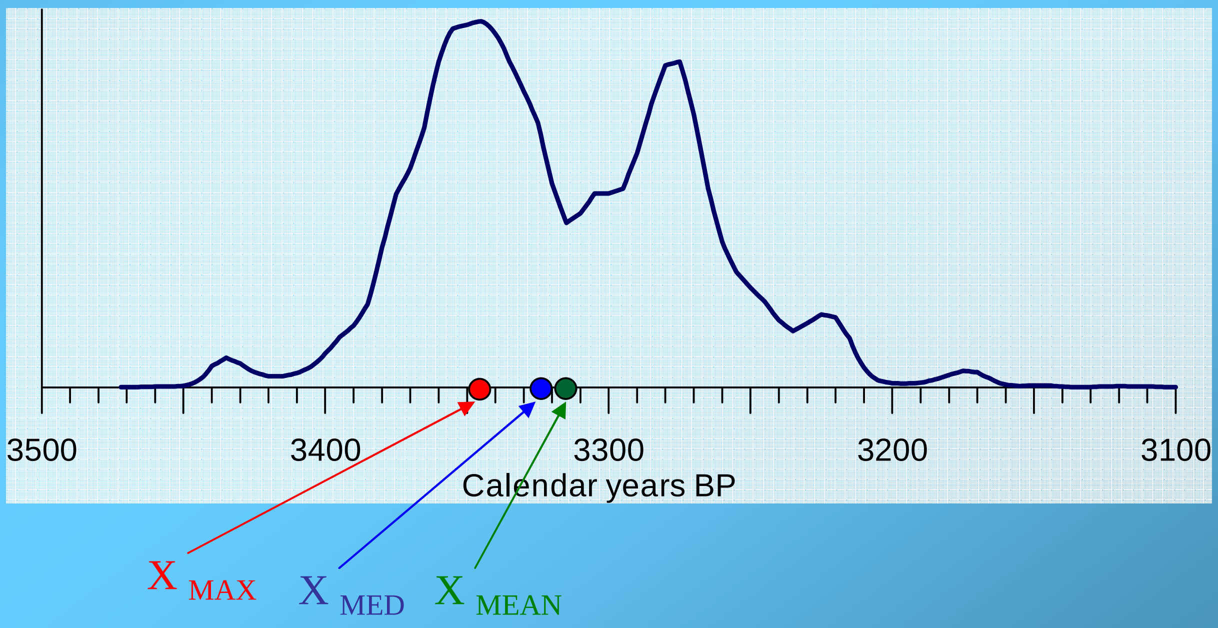
1. We assume value of true calendar age of sample – X_T.
2. The value X_T is transformed by calibration curve in order to find radiocarbon date X_R corresponding with X_T.
3. We assume value of error of radiocarbon date – σ.
4. The radiocarbon date $X_R \pm \sigma$ described by Gaussian probability distribution is calibrated and we obtain the probability distribution of calibrated radiocarbon date.
5. We estimate calendar age of sample by determining a few statistical parameters of the distribution and calculate difference between the value of parameter and true calendar age.



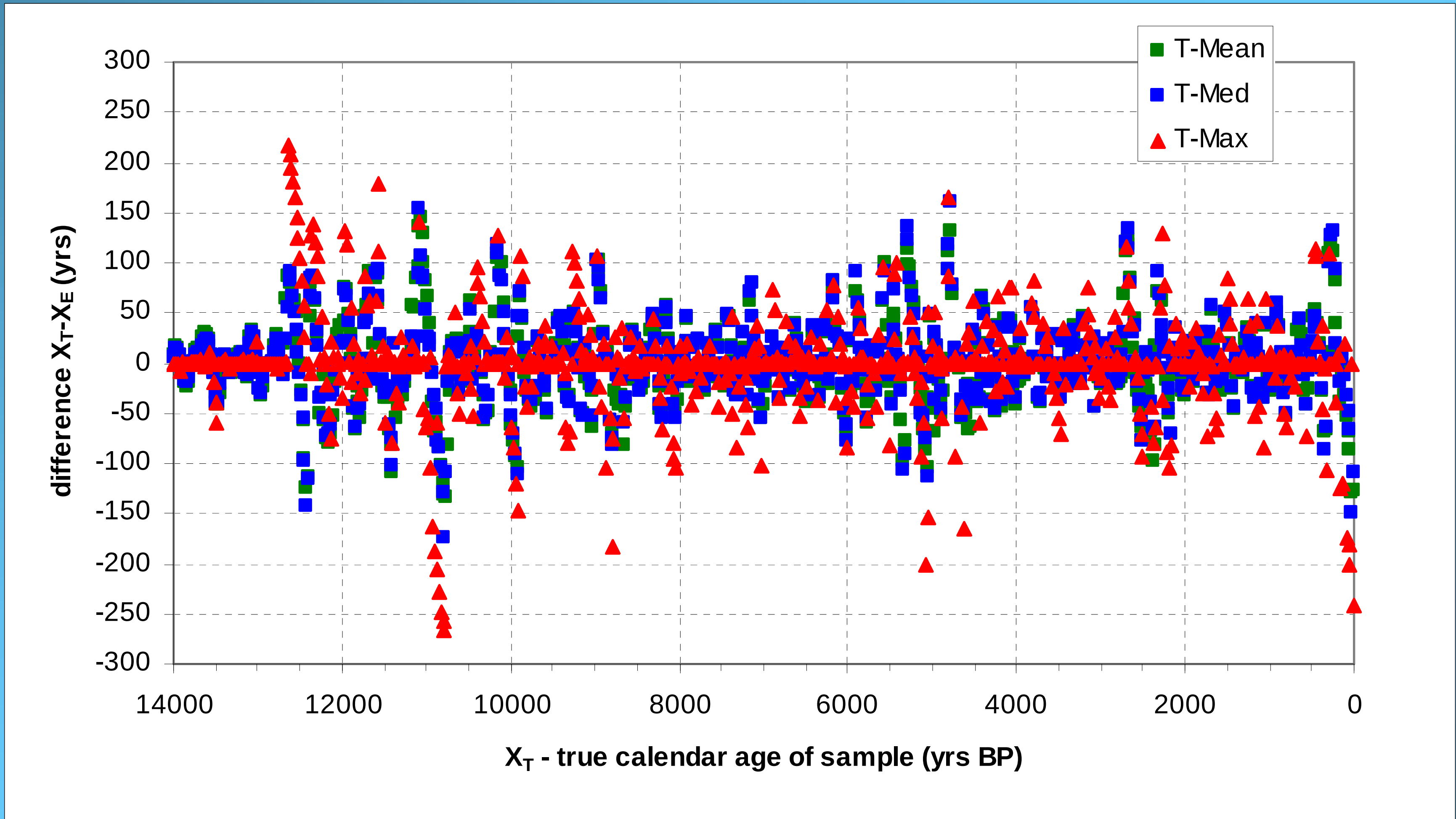
The parameters which are usually use for estimating the calendar age

Mode (X_{MAX}) – is a value which corresponds to maximum of distribution.
Median (X_{MED}) – is a value which divide distribution into two parts with the same probability (= 0.5)
Mean value or expected value (X_{MEAN}) is calculated as a weighted average of all possible values of age given by distribution, weighted by corresponding probability.

These three parameters have the same value for monomodal Gaussian distribution, but in another case their values become different.

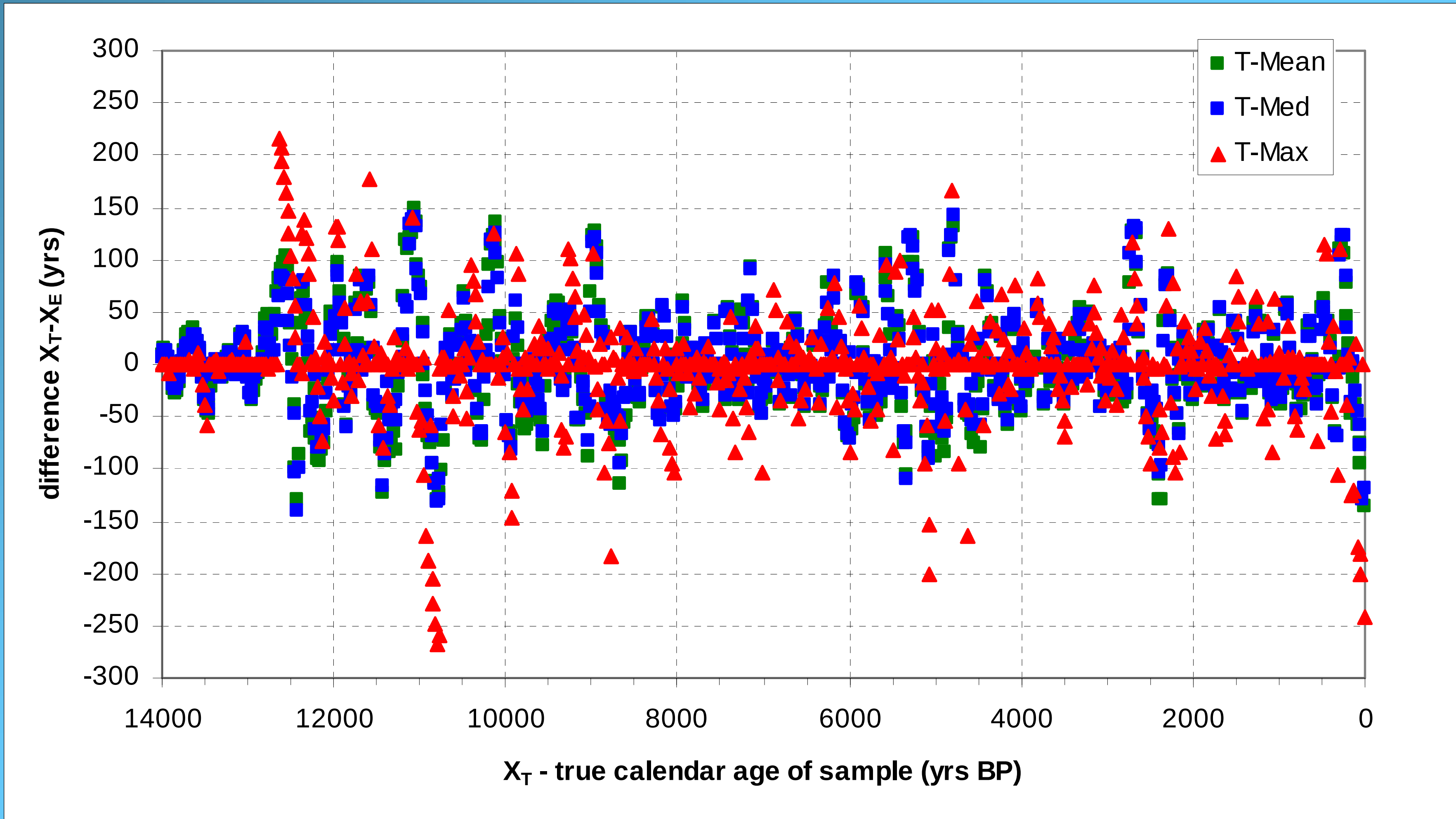


The difference between true (X_T) and estimated (X_E) calendar age of sample. Calculation for uncertainty (error) of radiocarbon date σ=25 yrs.



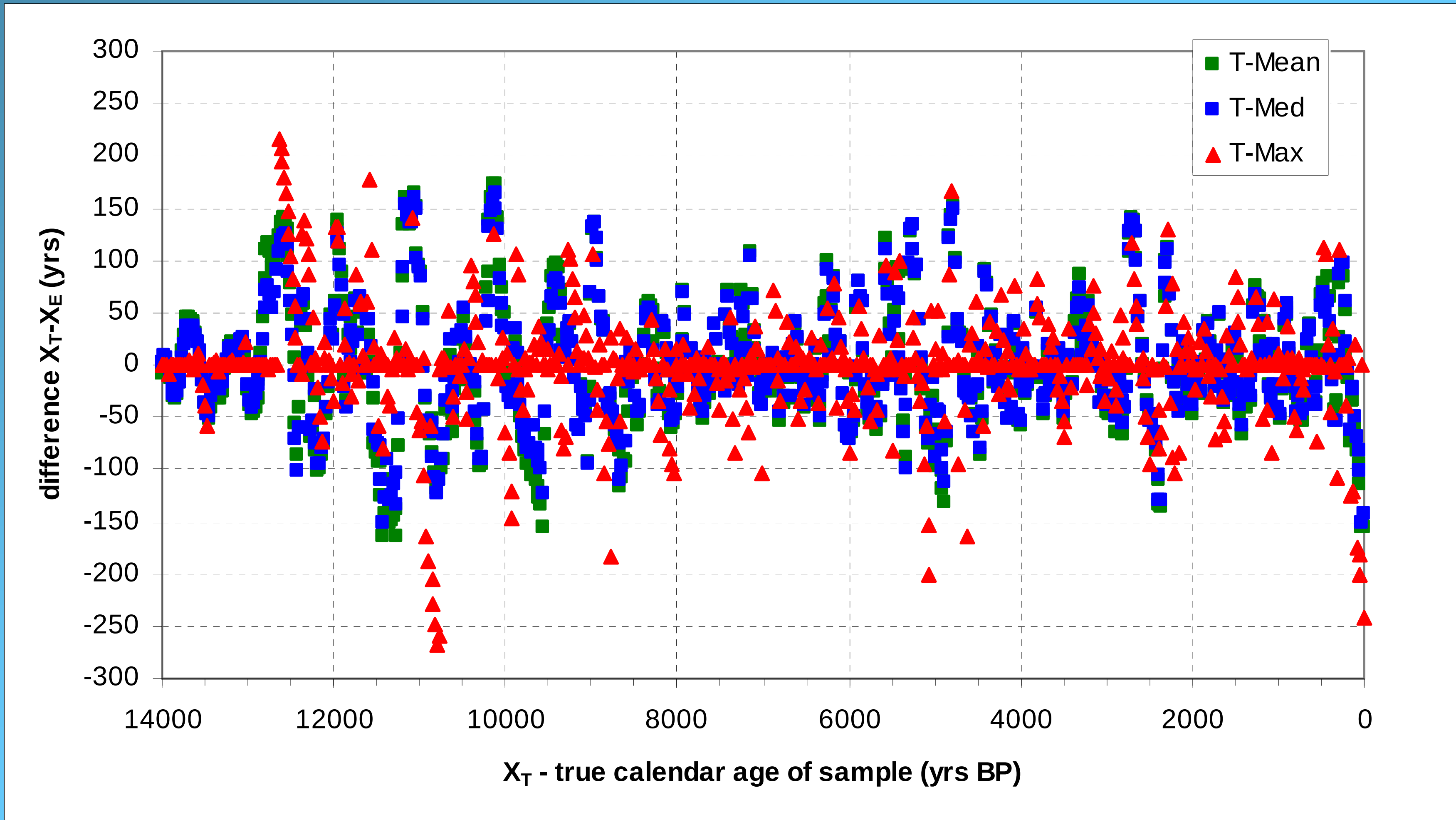
Red points show difference between true calendar age and maximum of probability distribution
Blue points show difference between true calendar age and median
Green points show difference between true calendar age and mean value.
Calculation were done using IntCal04 calibration curve (Reimer et.al., 2004).

The difference between true (X_T) and estimated (X_E) calendar age of sample. Calculation for uncertainty (error) of radiocarbon date σ=50 yrs



Red points show difference between true calendar age and maximum of probability distribution
Blue points show difference between true calendar age and median
Green points show difference between true calendar age and mean value.
Calculation were done using IntCal04 calibration curve (Reimer et.al., 2004).

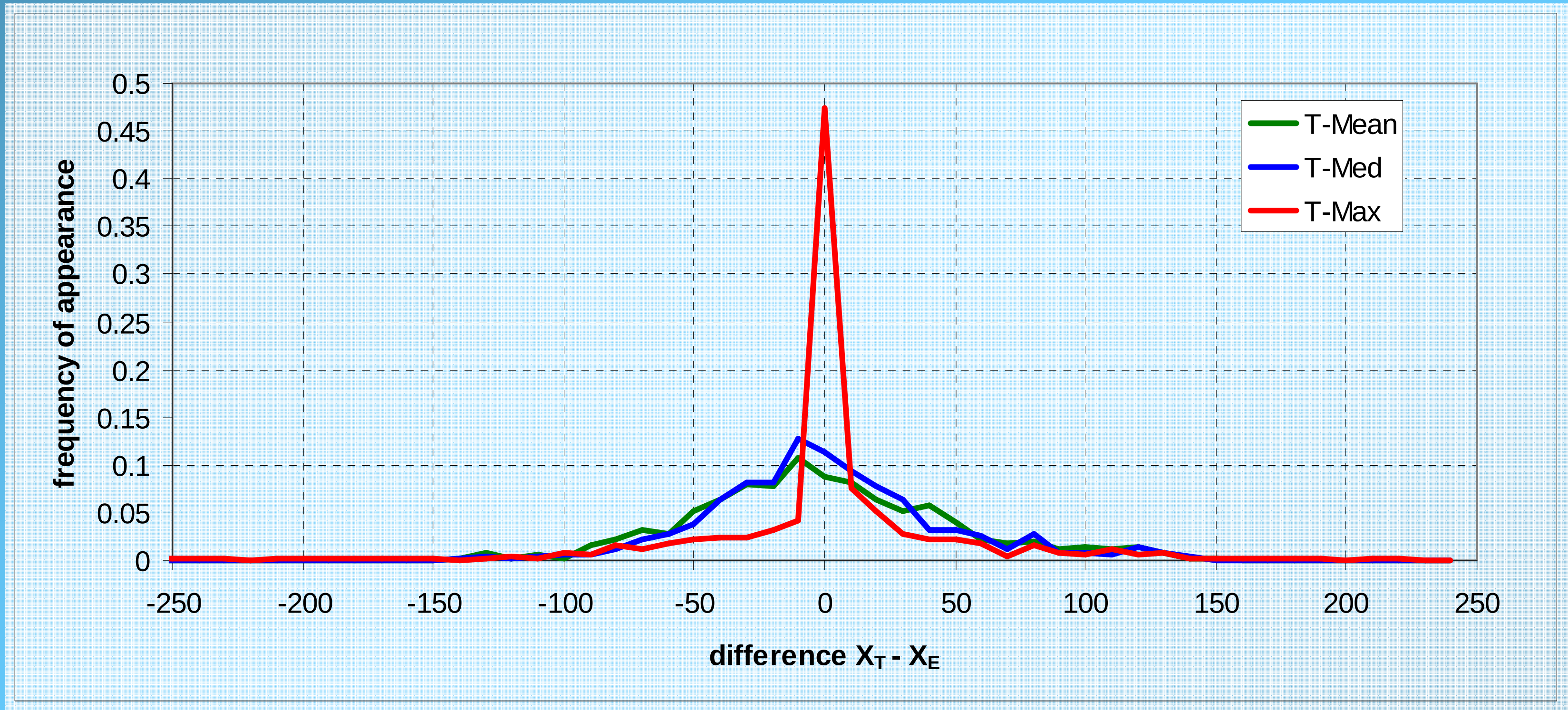
The difference between true (X_T) and estimated (X_E) calendar age of sample. Calculation for uncertainty (error) of radiocarbon date σ=100 yrs.



Red points show difference between true calendar age and maximum of probability distribution
Blue points show difference between true calendar age and median
Green points show difference between true calendar age and mean value.
Calculation were done using IntCal98 calibration curve (Reimer et al., 2004).

How often do these differences appear ?

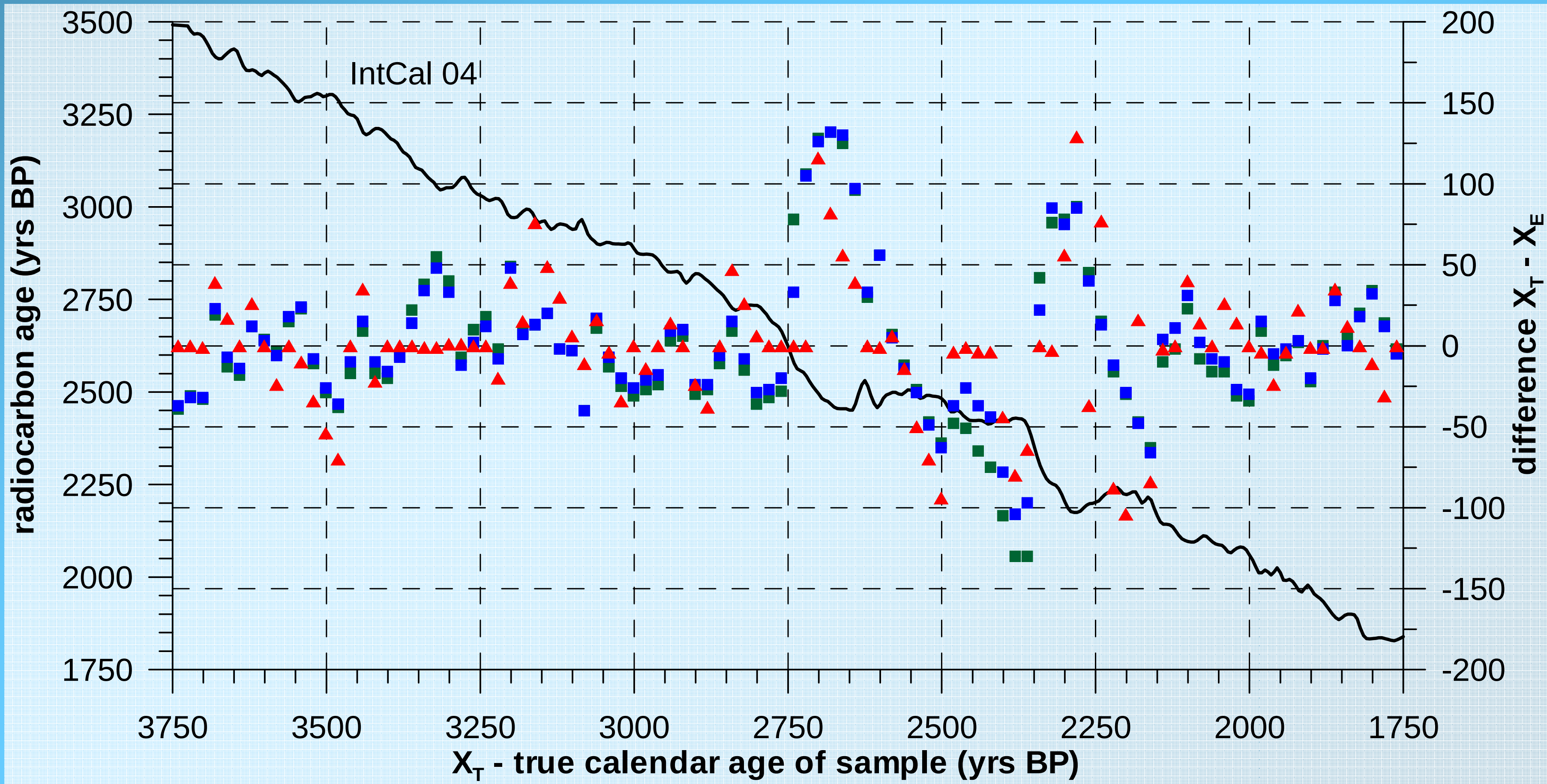
Figure presented below shows frequency of appearance of particular differences between true and estimated calendar age of sample for time period 0-14000 cal BP. **Red line** concerns maximum of probability, **blue line** concerns median and **green line** concerns mean value.



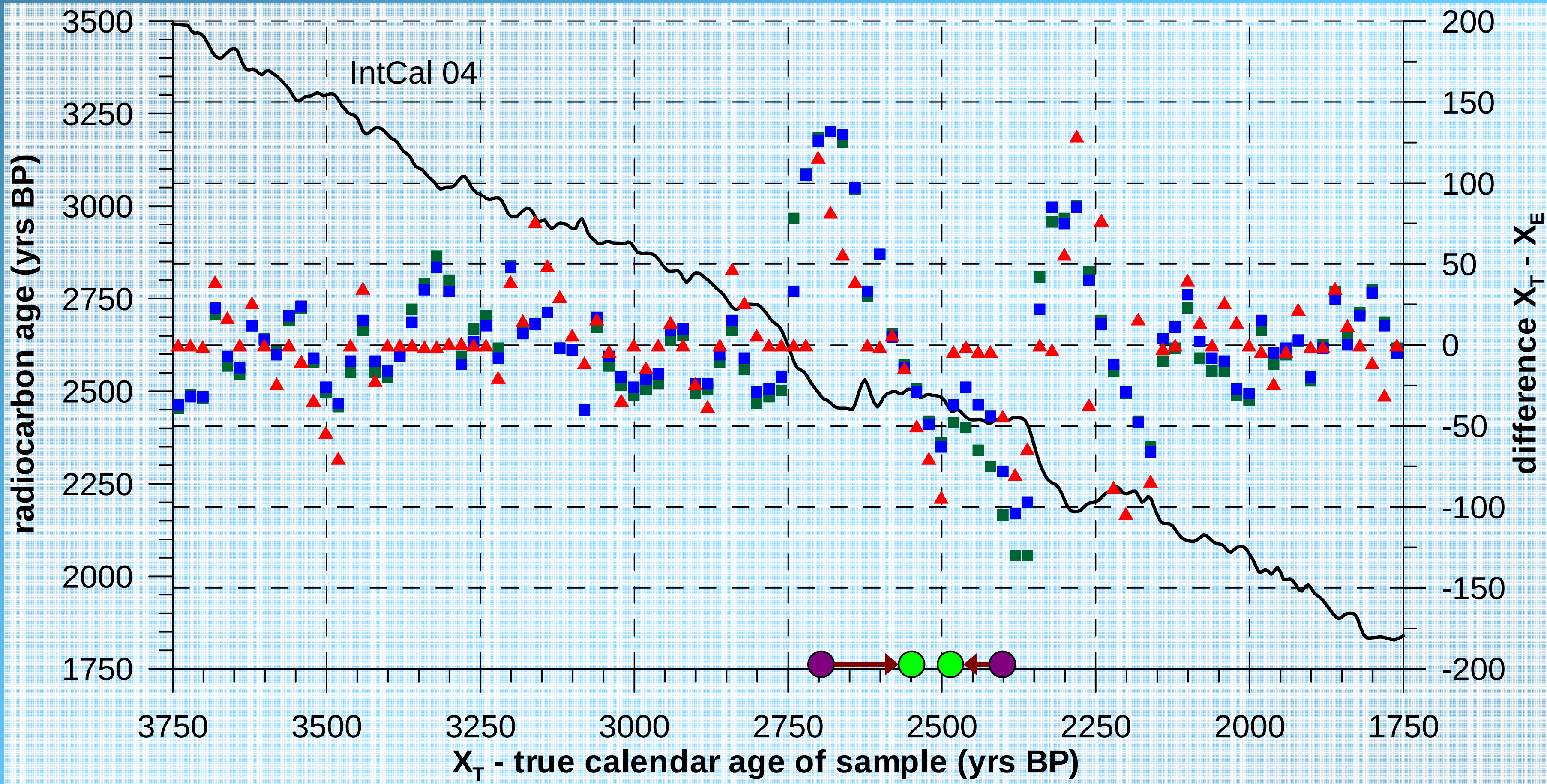
We may notice that the most often good concordance between true and estimated calendar age appear, when we estimate calendar age using maximum of probability distribution. The difference X_T-X_{MAX} for 47.5% cases is equal zero, and for 73% is less than ±35 yrs. However we could notice before, that for the maximum we can sometimes observe the largest differences between true and estimated calendar age.

Where do the greatest differences occur ?

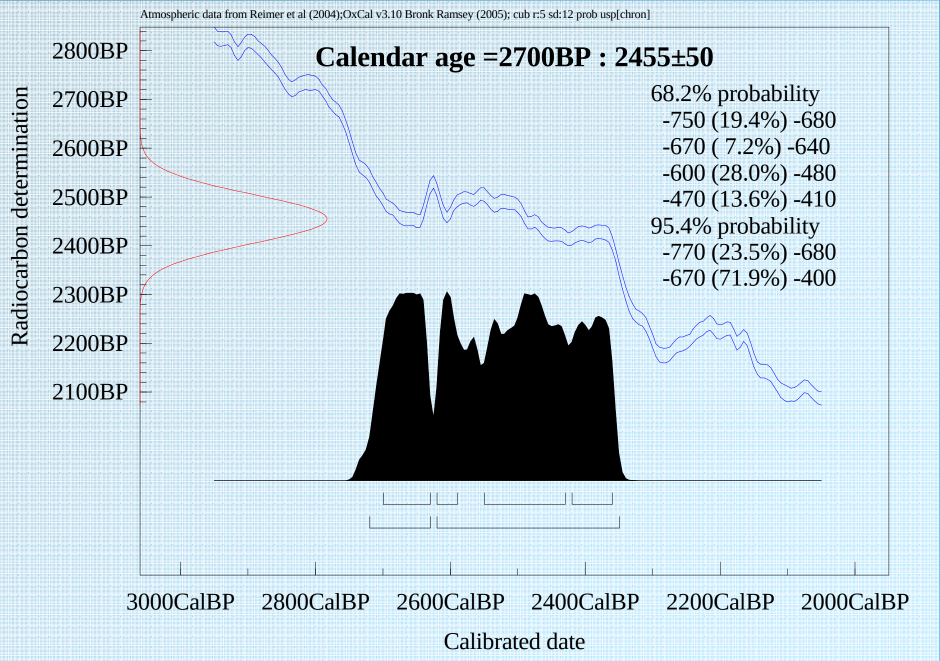
The greatest differences occur for these calendar years, where calibration curve has the large wiggles and rather flat areas with steep parts at the ends. The probability distributions of calibrated radiocarbon dates are in these cases multimodal or flat and significantly differ than Gaussian distribution.

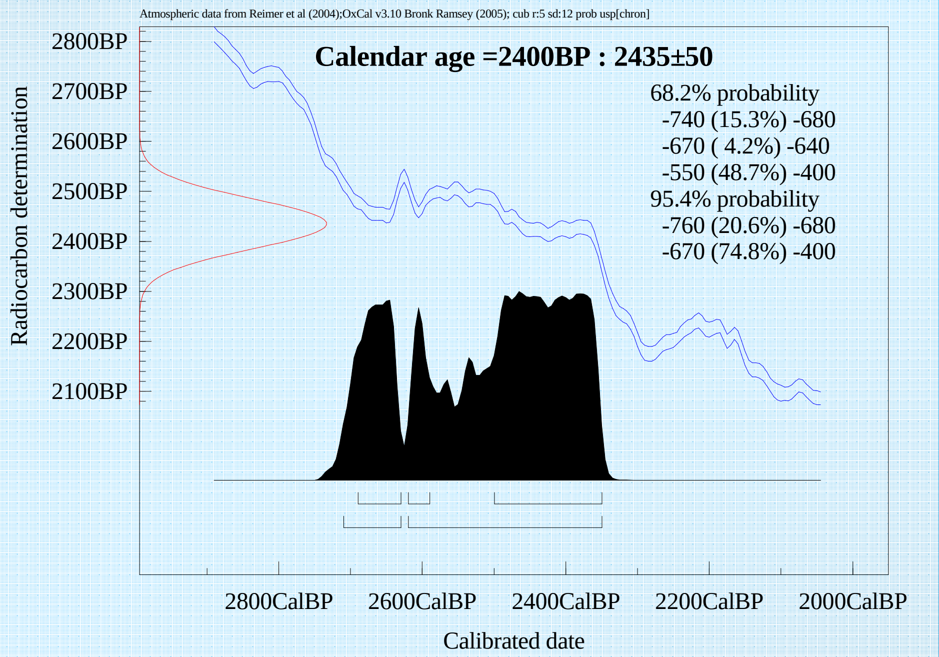


How may these differences affect on the chronology or time-depth model ?



Depending on which estimating parameter we choose, for a sample with true calendar age=2700BP we obtain the result shifted about 120-140 years towards smaller values of age, while for a sample with true calendar age=2400BP the results are shifted about 50-100 years towards greater values of age. Therefore estimated calendar age for both samples is almost the same and if we use these results for construction chronology or of age-depth model we draw wrong conclusions.



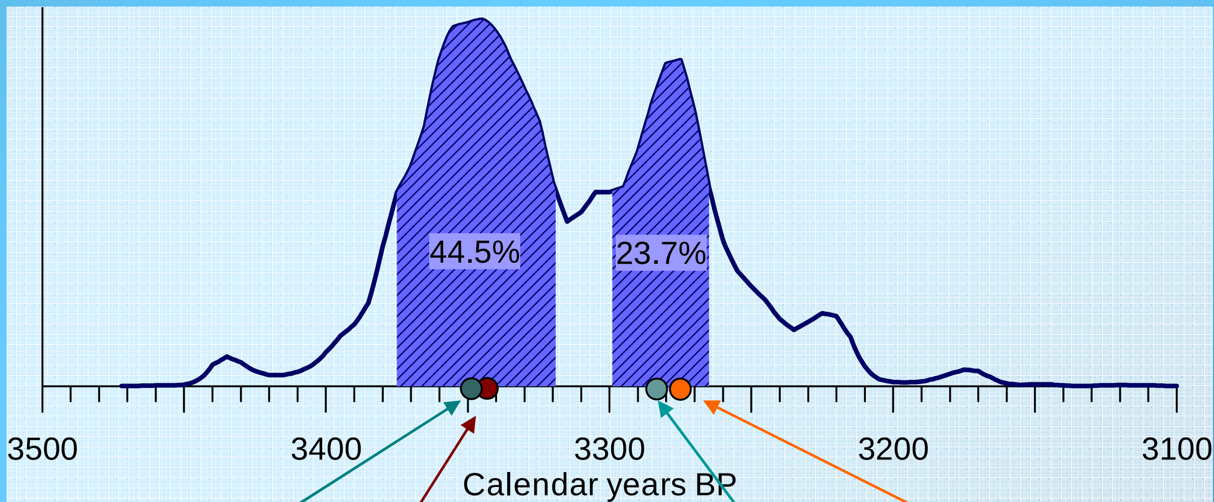


The reason of this effect is flat area of calibration curve which occurs between 2400 cal BP and 2700 cal BP (Hallstadt Period). It cause that probability distributions for radiocarbon dates related to this period are very wide, rather flat and cover almost whole period 2400 – 2700 cal BP.

The parameters which are usually use for estimating true calendar age of sample place themselves in the middle part of the distribution (even if the true calendar age is located at the end of distribution).

Another point estimates

There are also another point estimates, which are often used and should be discussed:
-Local mode (maximum) - value of age, which corresponds the highest of probability distribution included in 68.2% or 95.4% confidence interval,
-Middle (central point) of the confidence interval.
Because confidence intervals are often divided into a few parts, the above-mentioned point estimates were then calculated separately for each part. During this simulation only two the most important parts were taken into account – the most probable part of confidence interval (called afterwards the first part) and the second most probable part.
Simulation was done for 68.2% and 95.4% confidence intervals.



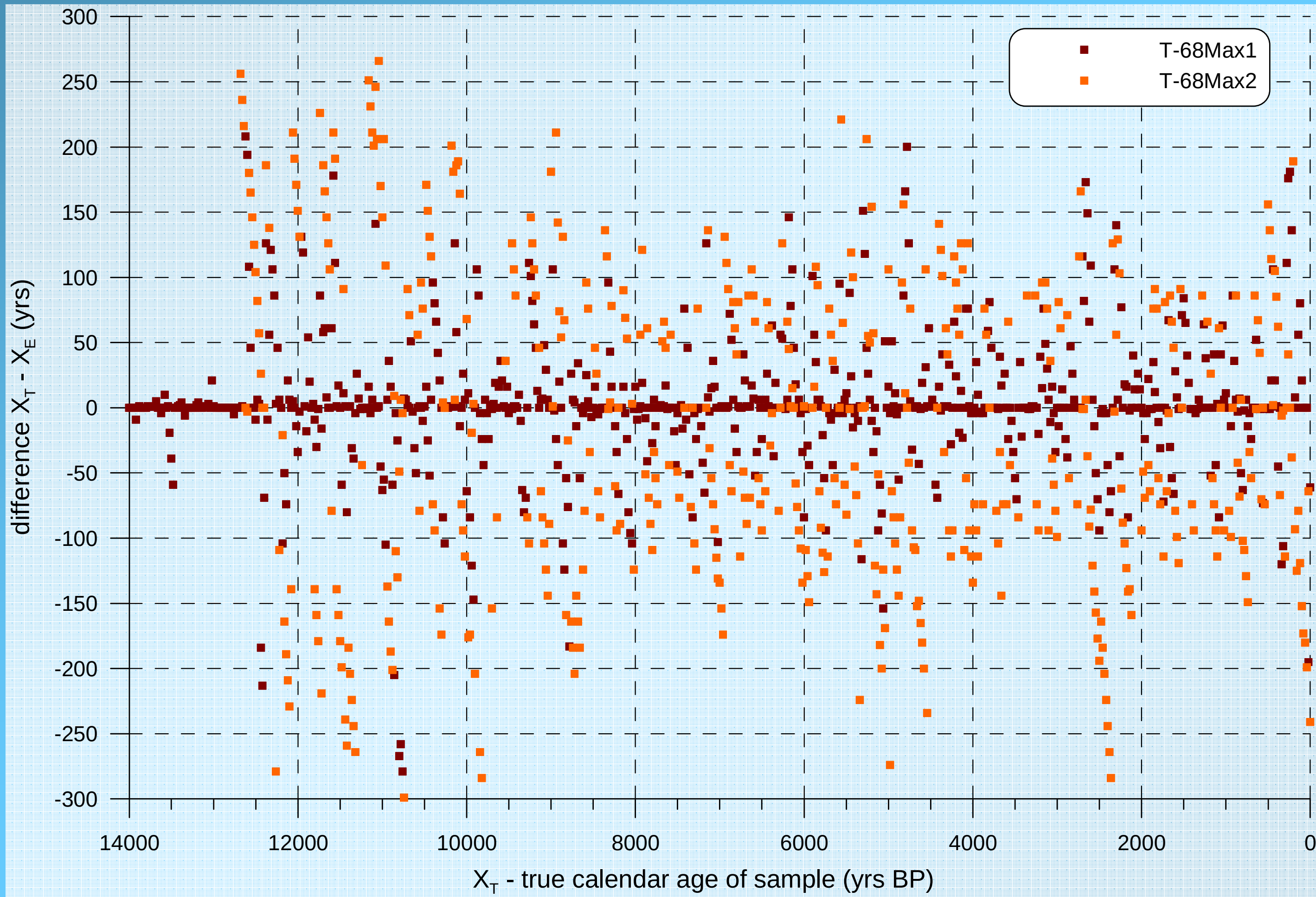
The middle of the first part of interval

The maximum of the second part of interval

The maximum of the first part of interval

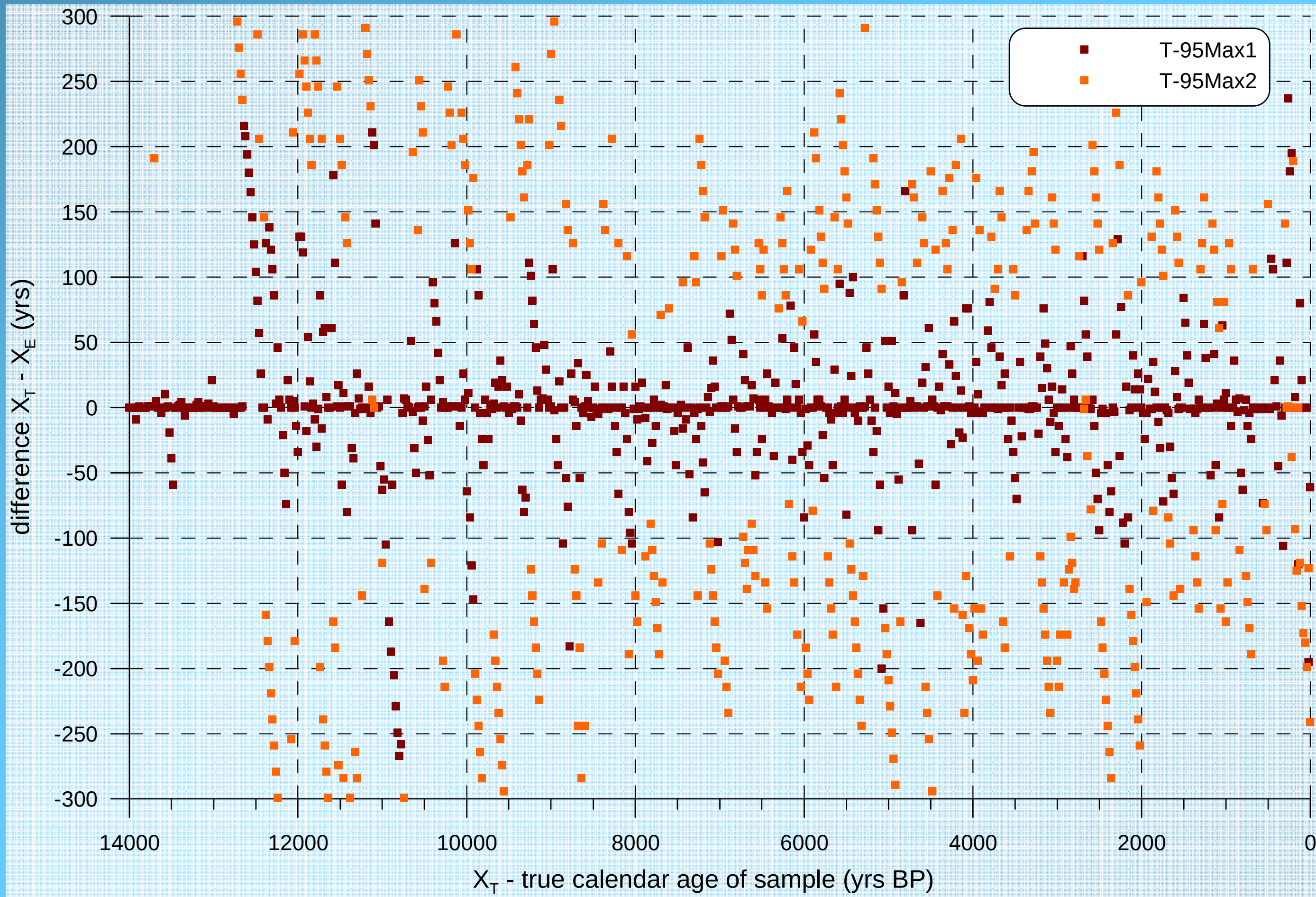
The middle of the second part of interval

The difference between true age and maxima of the first and the second part of 68.2% confidence interval. Uncertainty of radiocarbon date σ=50 yrs.



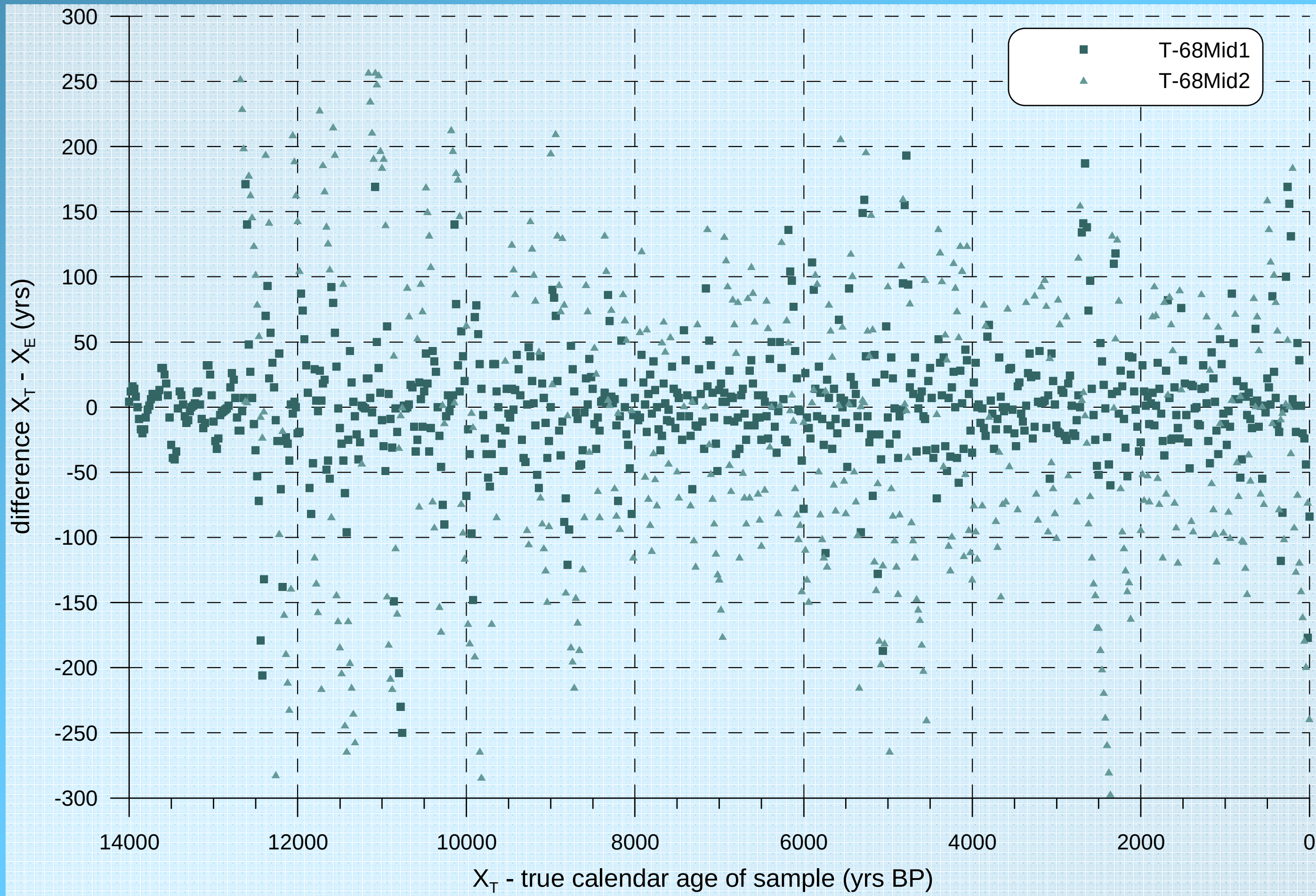
The differences for the maximum of the first part of interval are similar to the differences for the main maximum, because these maxima are usually equivalent. The maxima of the second part of interval mainly estimate true age of sample incorrectly, but sometimes they give correct value of the age o sample.

The difference between true age and maxima of the first and the second part of 95.4% confidence interval. Uncertainty of radiocarbon date σ=50 yrs

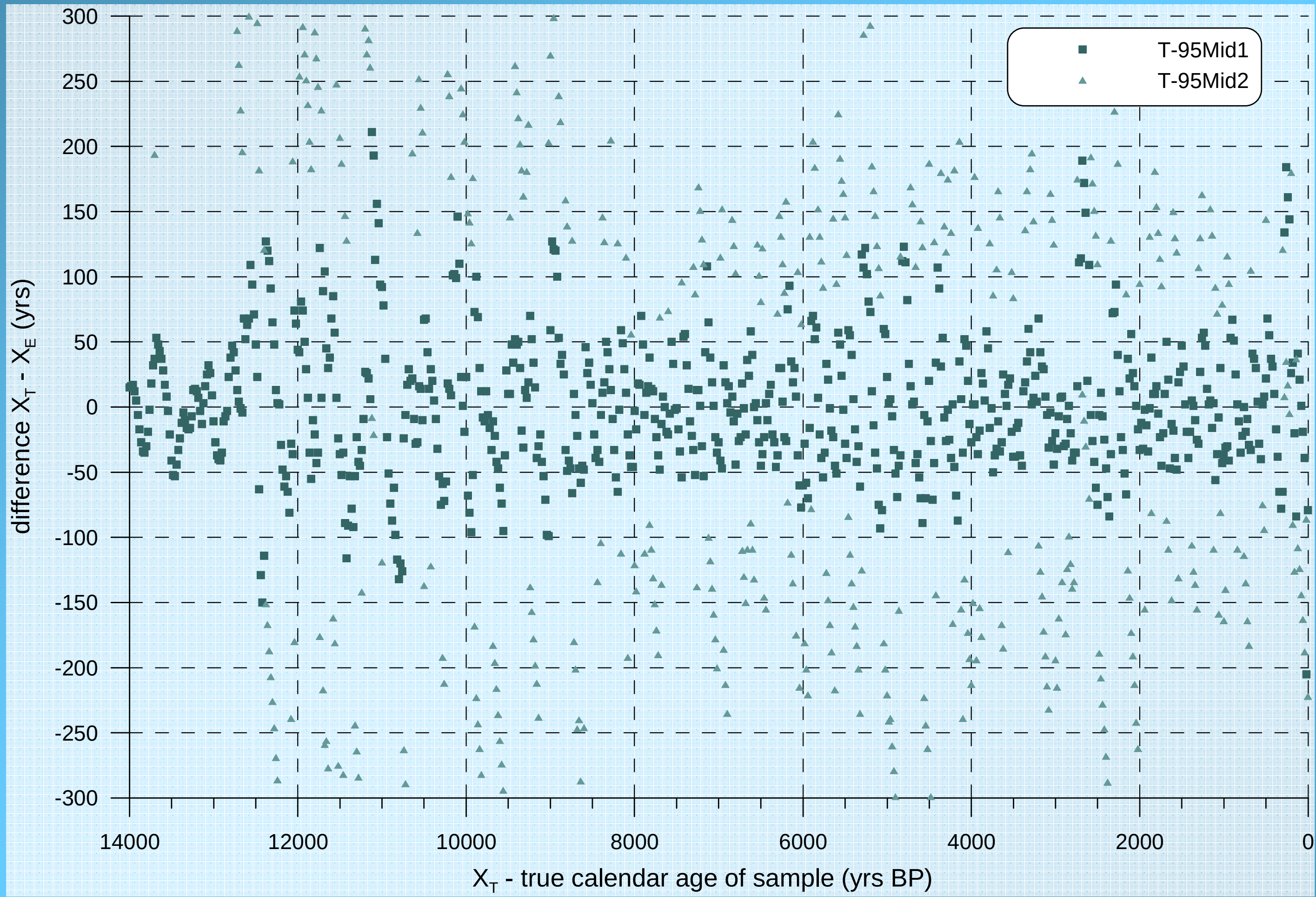


The maxima of the first part of 95.4% confidence interval and the main maxima are almost always equivalent. Both of them quite good estimate true age of samples apart from the time-periods where calibration curve has flat fragments. The maximum of the second part of 95.4% confidence interval estimates true age incorrectly.

The difference between true age and central points of the first and the second part of 68.2% confidence interval. Uncertainty of radiocarbon date σ=50 yrs.



The difference between true age and central points of the first and the second part of 95.4% confidence interval. Uncertainty of radiocarbon date σ=50 yrs



The results presented at this and previous transparency show, that central point of confidence interval is poor estimate of true calendar age.

Conclusions

The results of experiment show, that a very good method of point estimation of true calendar age does not exist. For all tested parameters one may observe differences between the true calendar age of sample and the value estimated using the parameter.

The maximum may be accepted as point estimate of calendar age of sample, but we should remember, that the differences between maximum and true age of sample may occur. However the important differences appear only for some periods, which are characterized by specific shape of calibration curve.

The use of another (than maximum) parameters for point estimation of calendar age may lead to wrong conclusion.

Therefore the best method of construction of chronologies or age-depth models would be such method, which use information about whole shape of probability distribution of each of dates.