

# Impulsive event probability in the radiocarbon record in VIII – XI centuries

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**Abstract.** The abundance of cosmogenic isotopes in natural samples is the main source of information about past variations of cosmic ray intensity, in the solar activity and in the strength of the geomagnetic field. Sharp increases could originate from powerful impulsive events such as solar flares, gamma-rays from supernova explosions and gamma-ray bursts. A significant increase in the radiocarbon record has been detected recently in tree rings around AD 775 [1]. Both large solar proton event (SPE) [2] and gamma-ray burst (GRB) in our Galaxy [3] are favored as a source. However, either of the explanations faces difficulties of low event rate because of detection of a similar peak around AD993 [4], [5]. What is more, we know other similar result [6]. We carried out a statistical analysis of these three data sets. It is shown that AD 775 event differs fundamentally from AD 993 and AD 1006 events, because the last two can be explained without the assumption of the impulsive event.

## 1. Data analysis technique

Record of  $\Delta^{14}\text{C}$  contains many signals corresponding to variations of known sources. Therefore, the main goal is to filter the data and estimate the probability of the presence of an independent statistically significant signal.

Allowance for the influence of the magnetic field of the Earth, and long-term variations in solar activity, is carried out by subtraction of calibration curve IntCal09 from data [7]. If a statistically significant jump is detected, the correlation coefficient between the data and a profile corresponding to the case of impulsive event is estimated. The profile is taken from [3]. It should be pointed out, that authors of [3] had to modify the exchange rates of carbon cycle model to obtain the desired profile.

Since we do not have information about solar activity during that period, the modulating effects of solar activity on the Galactic Cosmic Ray (GCR) flux are taken into account as follows: a sine wave is chosen using the least squares method. Then its amplitude and period are compared with the measured values [8].

Data obtained as a result of the subtraction of the calibration curve and the best fit sine wave, are analysed by a normality test to determine if statistically significant signal is present.

## 2. Results

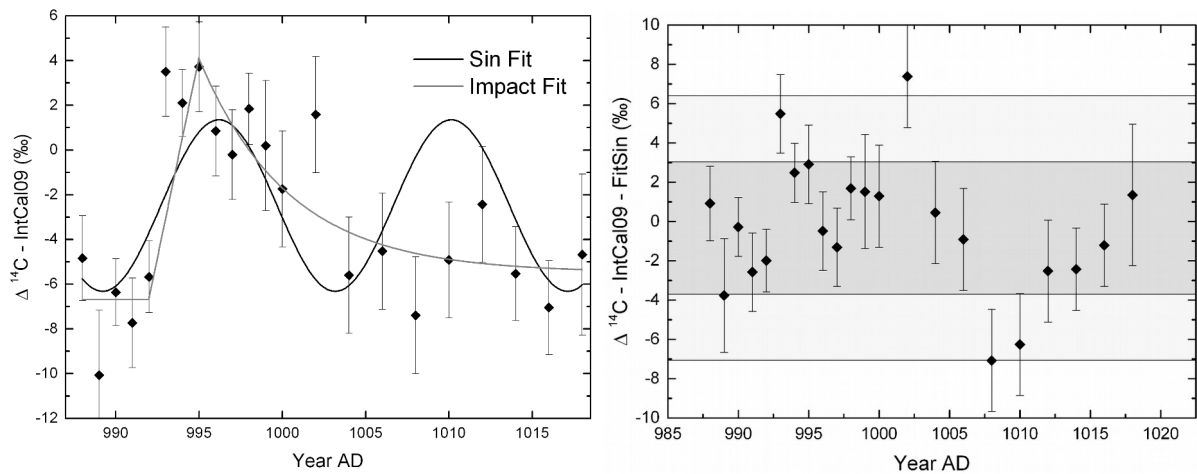
Analysis of the data around AD 993 (figure 1) showed a large value of the correlation coefficient between the data and a profile corresponding to the case of impulsive event ( $r_1 = 0.82$ ). Best fit sine wave period was equal to  $T = 14 \pm 1.1$  years, the amplitude  $A = 3.8 \pm 1 \text{ ‰}$ , which is consistent with



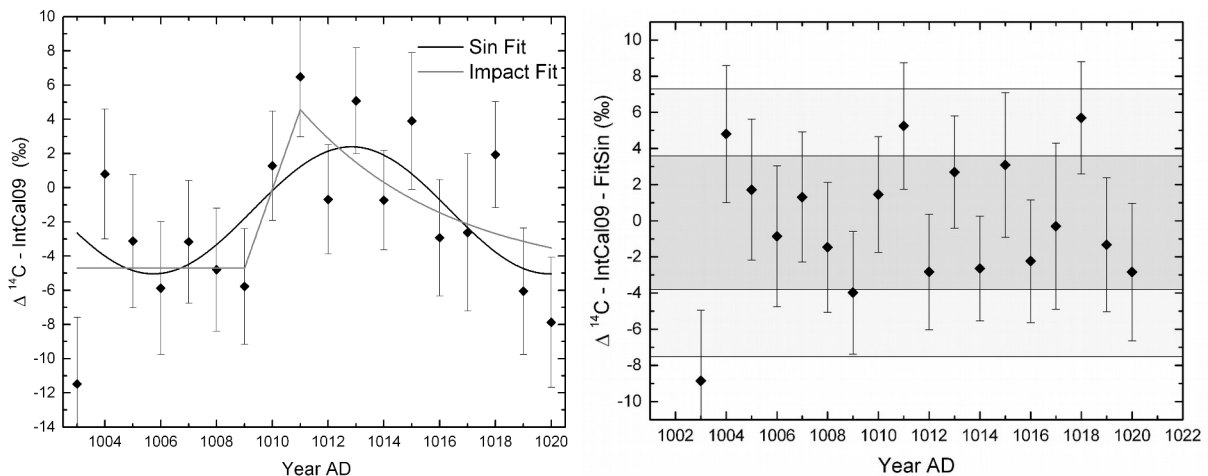
the observational data [8]. Thus, the shape of the curve can also be explained by the influence of solar modulation, namely the 11 year cycle ( $r_2 = 0.57$ ). Consequently, the analysis result does not let us conclusively assert that the impulsive event had been registered around AD 993.

A similar conclusion was obtained by considering a record of  $\Delta^{14}\text{C}$  around AD 1006 (figure 2) ( $r_1 = 0.71$ ,  $r_2 = 0.62$ ). The best fit sine wave parameters are  $T = 14.2 \pm 1$  years,  $A = 3.7 \pm 1.3$  ‰.

Joint analysis of the data around AD 993 and AD 1006 demonstrated the coordination in the localization of sine wave and its parameters within the error limits ( $T = 14$  years,  $A = 3.9 \pm 0.8$  ‰). This result is a powerful argument for explaining the shape of the curve  $\Delta^{14}\text{C}$  by the influence of solar modulation, especially due to the fact that these two data sets were obtained at different times in different laboratories using different samples. The result does not contradict the indirect data for solar activity in the past [9].



**Figure 1:** Data around AD 993. (Left) data obtained as a result of the subtraction of the calibration curve; (right) data obtained as a result of the subtraction of the calibration curve and the best fit sine wave.

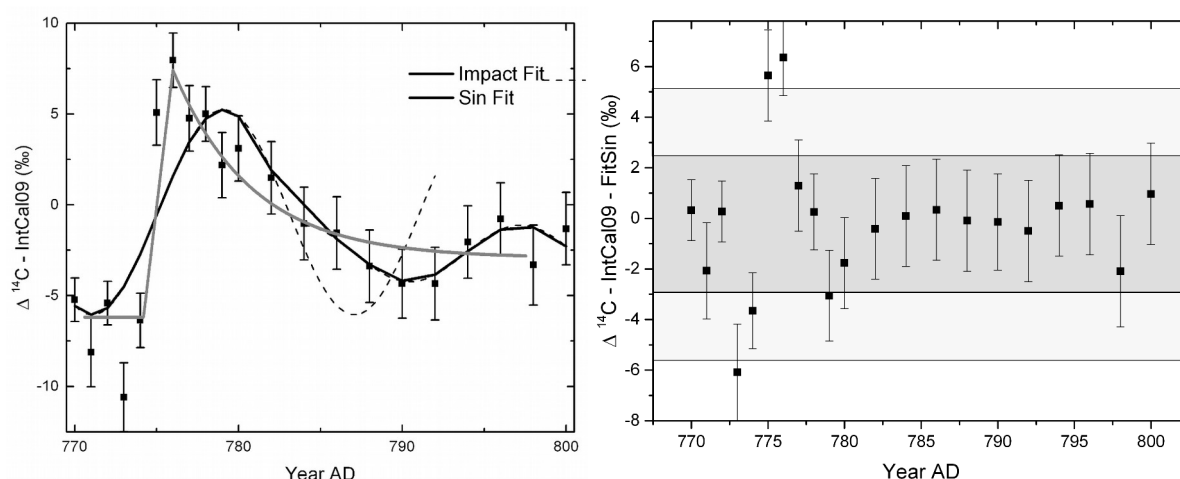


**Figure 2:** Data around AD 1006. (Left) data obtained as a result of the subtraction of the calibration curve; (right) data obtained as a result of the subtraction of the calibration curve and the best fit sine wave.

The correlation coefficient between the data around AD 775 (figure 3) and a profile corresponding to the case of impulsive event is extremely high ( $r_1 = 0.93$ ). When we try to localize the wave of 11 year cycle the sine wave was obtained with parameters  $T = 22.6 \pm 2$  years,  $A = 5.3 \pm 1.2$  ‰. These values do not allow us to treat it as a reflection of the 11 year solar modulation.

As a result of approximation with allowance for variability of solar cycle parameters a curve which is in good agreement with the experimental data was obtained ( $r_2 = 0.82$ ). Its parameters are in reasonable agreement with 11 year cycle characteristics ( $A_1 = 5.6 \pm 1.2 \text{ ‰}$ ,  $T_1 = 16 \pm 1.8$  years,  $A_2 = 1.6 \pm 0.5 \text{ ‰}$ ,  $T_2 = 13.4 \pm 1.8$  years). Data obtained as a result of the subtraction of the calibration curve and modified sine wave are not a noise, but do contain a statistically significant signal with high probability.

It can therefore be concluded that AD 775 event can not be explained as a result of coaction of known permanent sources.



**Figure 3:** Data around AD 993. (Left) data obtained as a result of the subtraction of the calibration curve; (right) data obtained as a result of the subtraction of the calibration curve and modified sine wave.

### 3. Conclusions

Based on the analysis of high-resolution records of  $\Delta^{14}\text{C}$  in tree rings in periods of 770-800, 988-1018 and 1003-1020 AD we came to the following conclusions:

1. AD 993 and AD 1006 events can be explained as a result of coaction of known permanent sources that affect the  $^{14}\text{C}$  production rate, and can not be definitely interpreted as a response to an impulsive event.
2. AD 775 event differs fundamentally from AD 993 and AD 1006 events, because it can not be explained without the assumption of the impulsive event.
3. The main objection to the two most likely causes of events 775 is removed.

### References

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