Impact of solar activity on the growth of pine trees (Pinus cembra: 1610 – 1970; Pinus pinaster: 1910 – 1989)

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Abstract
In this work we focused on analysis of the data for the annual growth of cembra pine (*Pinus cembra*) grown in the North of Slovakia. The database covers the period of 1406 - 1970, but sunspot data (minima and maxima), is only available since 1610 at the NGDC site. Moreover, the most reliable sunspot numbers data are only from 1749. The results of this analysis agree with the observation in the previous work, i.e. negative impact of high SA on growth, but it should be noted, however, that the statistical significance of results is low. We applied also wavelet analysis to data on the evolution of tree growth, the results indicate periodic variations in the growth period of about 25 years (duration of approximately two solar cycles or one magnetic cycle, respectively), also periodicities of 30, 35, and 70 years were observed. A negative impact of the SA was also observed, in the growth of a 90 year-old maritime pine (*Pinus pinaster*) tree grown in the North of Portugal. The width of the annual rings was smaller in the years of maximum SA; furthermore it was found that it is the latewood growth that it is affected while the earlywood growth is not affected, as a corollary the percent of late wood also shows a significative negative correlation with SA.

1. INTRODUCTION

Many studies indicate that the solar activity (SA) can affect tree growth induced by changes in climatic conditions on Earth's surface evoked due to SA variations (e.g. Rigozo et al., 2008; Feng and Han, 2009; Nicolussi et al., 2009). The SA variations were significantly lower during 1994-1995 (SA minimum) than for the more recent period covering 1999-2001 (SA maximum). Satellite measurements revealed during the past decades the variability of the solar „constant" (in average of ~0.1 % during a sunspot cycle).

In the previous work, Surový et al. (2008), we found that:

- cork oak (*Quercus suber L.*) bark growth was lower in the period of higher solar activity than in the period of lower solar activity.
- the highest correlation between the SA and the bark growth was in the period from July of one year to June of the following year.

In this paper we investigated relationship between the 11-year solar cycles and the pine trees growth using data sets of annual growth of cembra pine (*Pinus cembra*) and of maritime pine (*Pinus pinaster*).

2. INPUT DATA AND METHODS

We used the following input data in our analysis:
1. annual growth of cembra pine (*Pinus cembra*), 1406 – 1970, provided by P. Fleischer, Research Station and Museum TANAP, Tatranská Lomnica, Slovak Republic.
2. annual growth of of maritime pine (*Pinus pinaster*), 1910-1989, provided by J. L. Lousada, Universidade

Trás-os-Montes e Alto Douro (UTAD), Vila Real, Portugal.
3. sunspot data (dates of minima and maxima), is only available since 1610 (NGDC site); the most reliable sunspot numbers data are only from 1749.

We investigated relationship between the 11-year solar cycles and the pine trees growth studying data distributions, long-term trends in data fits and performing wavelet analysis.

3. RESULTS

***Pinus cembra* (cembra pine)**

In Figure 1 is shown overall evolution of this pine tree growth and in Figure 2 is detailed comparison of the growth evolution with sunspot numbers.

We defined so-called Growth Dynamics Index (GDI) as a ratio of the measured growth (MG) and the theoretical growth (TG): GDI = MG / TG) (theoretical growth), where TG is calculated according to equation: y = 552.86x - 0.5064.

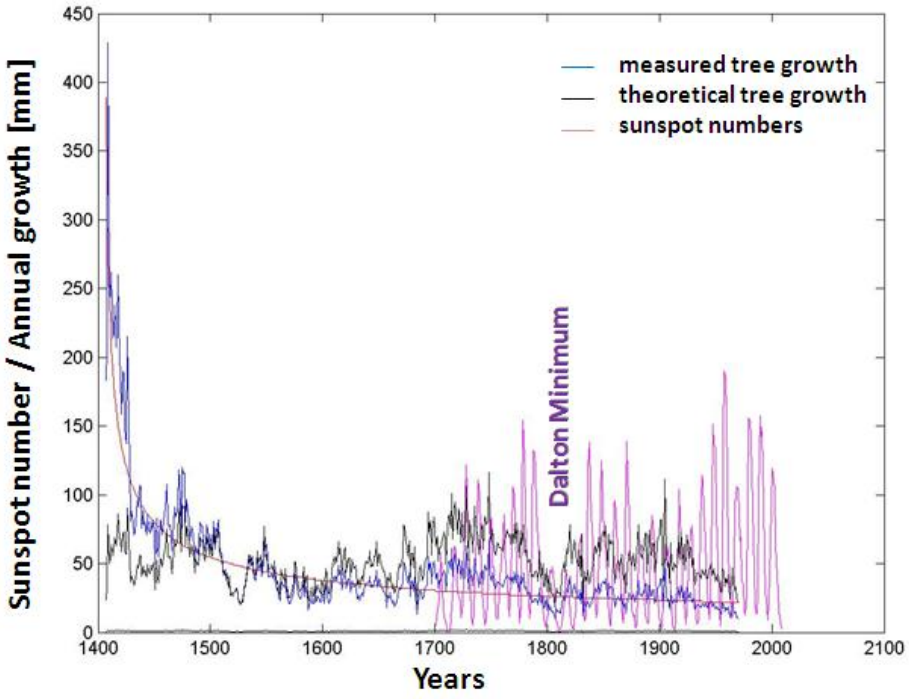


Fig. 1. Evolution of the pine tree growth (1406 – 1970) and sunspot numbers (1700 – 2009).

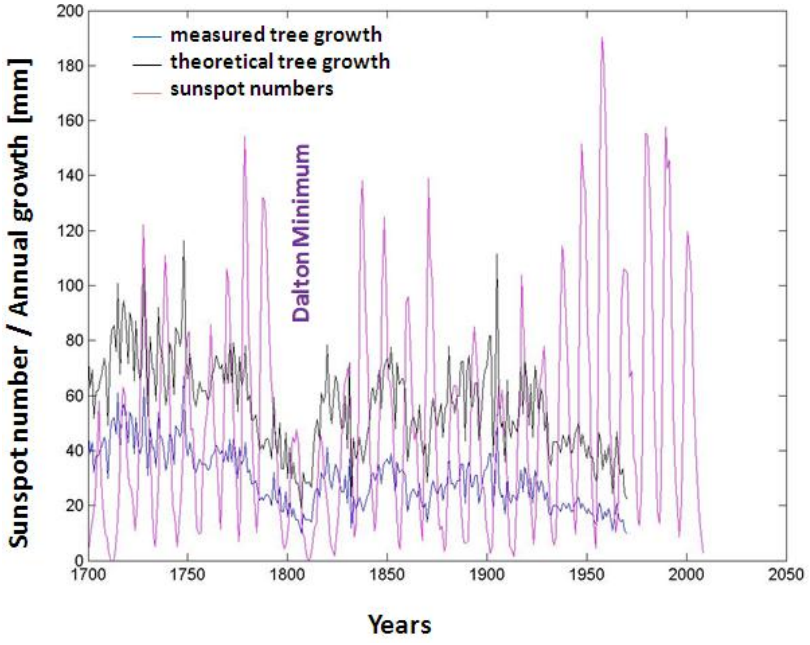


Fig. 2. Evolution of the pine tree growth and sunspot numbers (1700 – 1970).

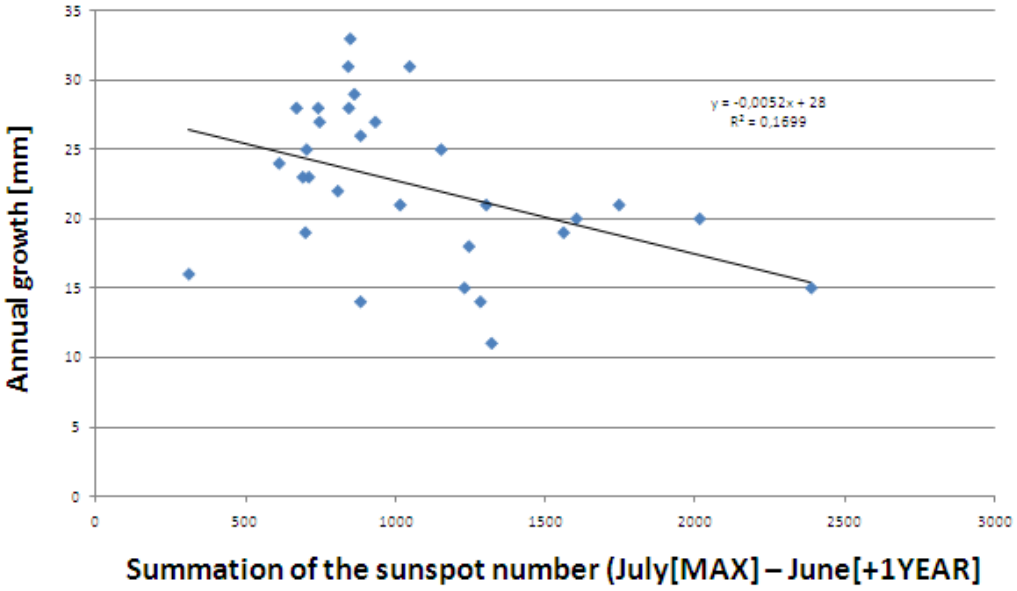


Fig. 3. Distribution of annual growth of the pine tree in the periods of SA maxima as a function of the summation index of the sunspot number.

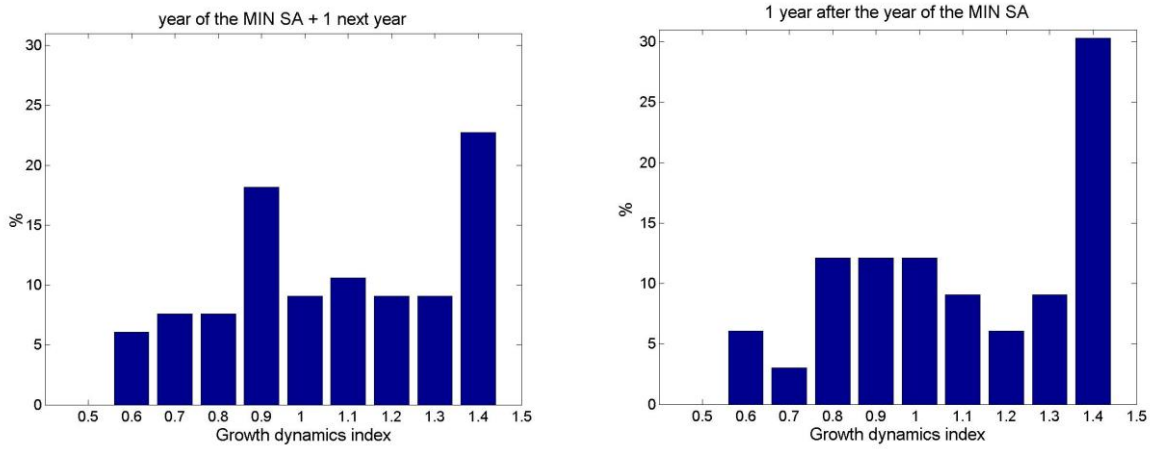


Fig. 4. Distribution of the growth dynamics index for the periods of SA minima.

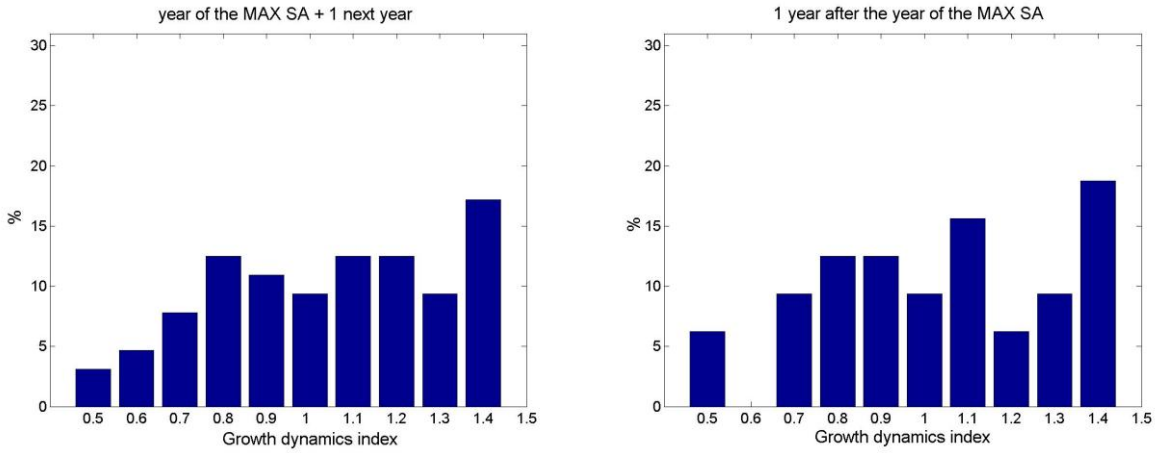


Fig. 5. Distribution of the growth dynamics index for the periods of SA maxima.

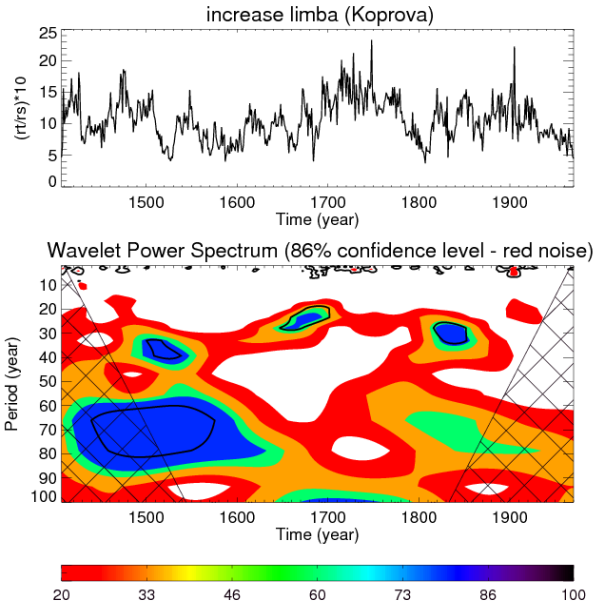


Fig. 6. Wavelet power spectrum (1406-1970). Significant periods found: 25, 30, 35, and 70 years.

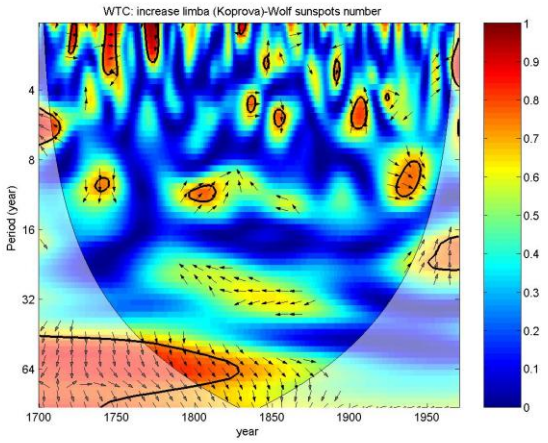
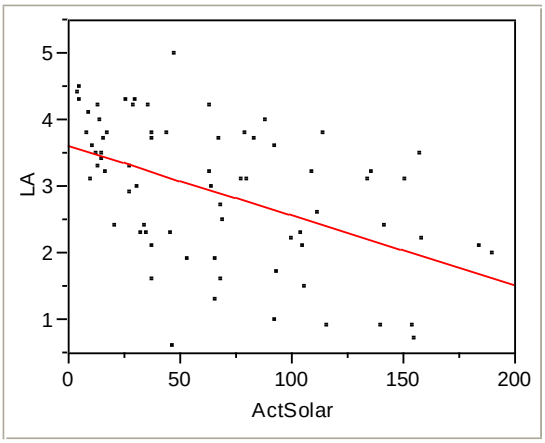


Fig. 7. Wavelet coherence with Wolf sunspot number (1700-1970). Significant coherence: 1700-1825, period of 64 years, phase from 90° to 50°; only sporadic coherence at lower periods.

***Pinus pinaster* (maritime pine)**



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	6800,751	6800,75	71,8738
Error	70	6623,455	94,62	Prob > F
C. Total	71	13424,205		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	54,857702	1,922325	28,54	<.0001
ActSolar	-0,197078	0,023246	-8,48	<.0001

Linear Fit LA = 3,630012 - 0,0104115 ActSolar RSquare: 0,238716 R= 0.49

Fig. 8. Bivariate fit of the annual growth (LA) of the maritime pine by the solar activity (ActSolar).

There is a highly significant (p value < 0.0001) negative correlation between sunspot activity and annual growth rings (R=0.49) for the period 1925-1980. The initial period from 1910 to 1925 corresponding to the development of juvenil wood was not considered in the analysis.

4. DISCUSSION AND CONCLUSIONS

We have observed similar behaviours as in our previous work, i.e. that the tree growth seems to be higher in the periods of SA minima than in the periods of SA maxima. However, statistical significance is low. Possible explanation of this coupling could be photoassimilation in trees: high SA can affect the assimilation process in the tree growth.

Acknowledgements

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