XIII[th] Bulgarian-Serbian Astronomical Conference, 3-7 October 2022, Velingrad, Bulgaria

Wavelet Coherence of Total Solar Irradiance and Atlantic Climate Oscillation

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OBJECTIVES

- Determination of coherence between solar activity and climate over Atlantic Ocean

USED DATA

- Total Solar Irradiation (TSI)
- Atlantic Multidecadal Oscillation (AMO)

METHODS

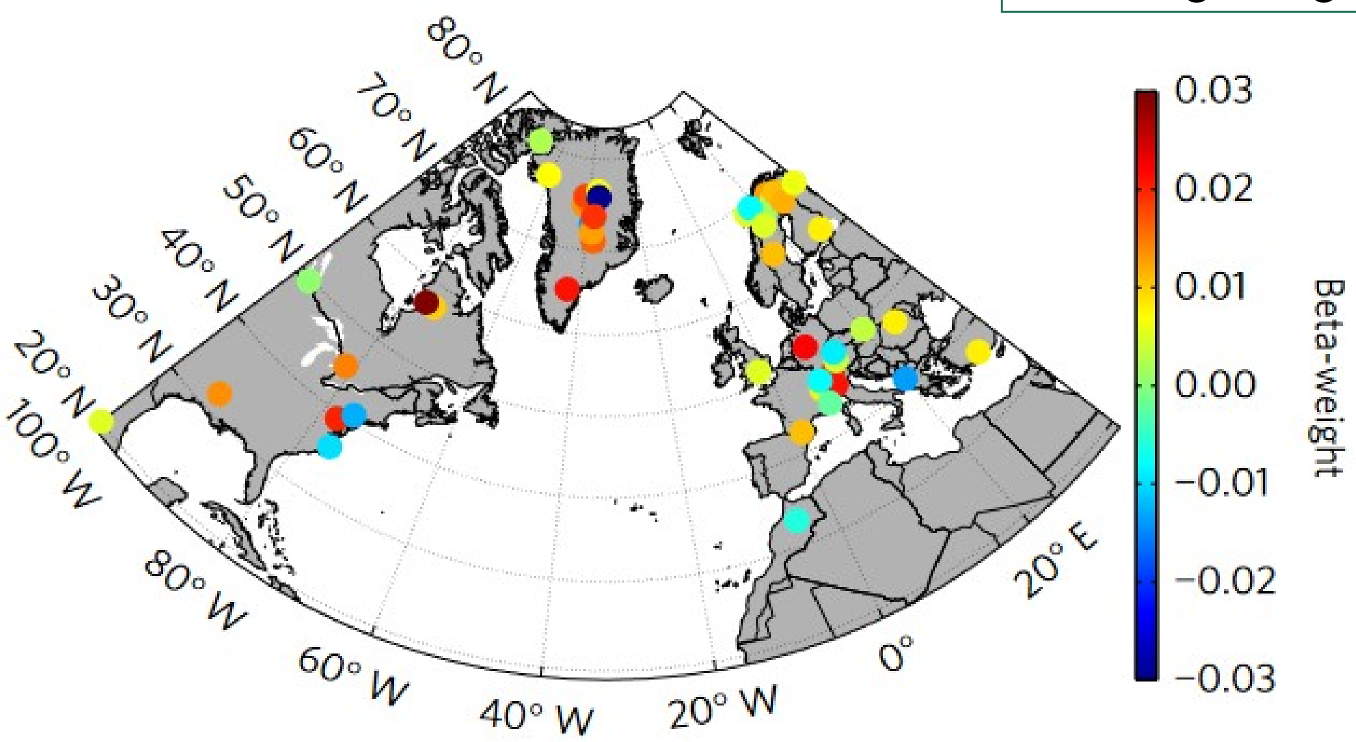
- Partial Fourier Approximation, Continuous Wavelet Transform, Wavelet Coherence;

RESULTS

- Long-term coherence between TSI and AMO over millennial time scale since 800 AD

AMO data

Region 20N-80N; 100W-35E of AMO data determination, according Wang et al. (2017).



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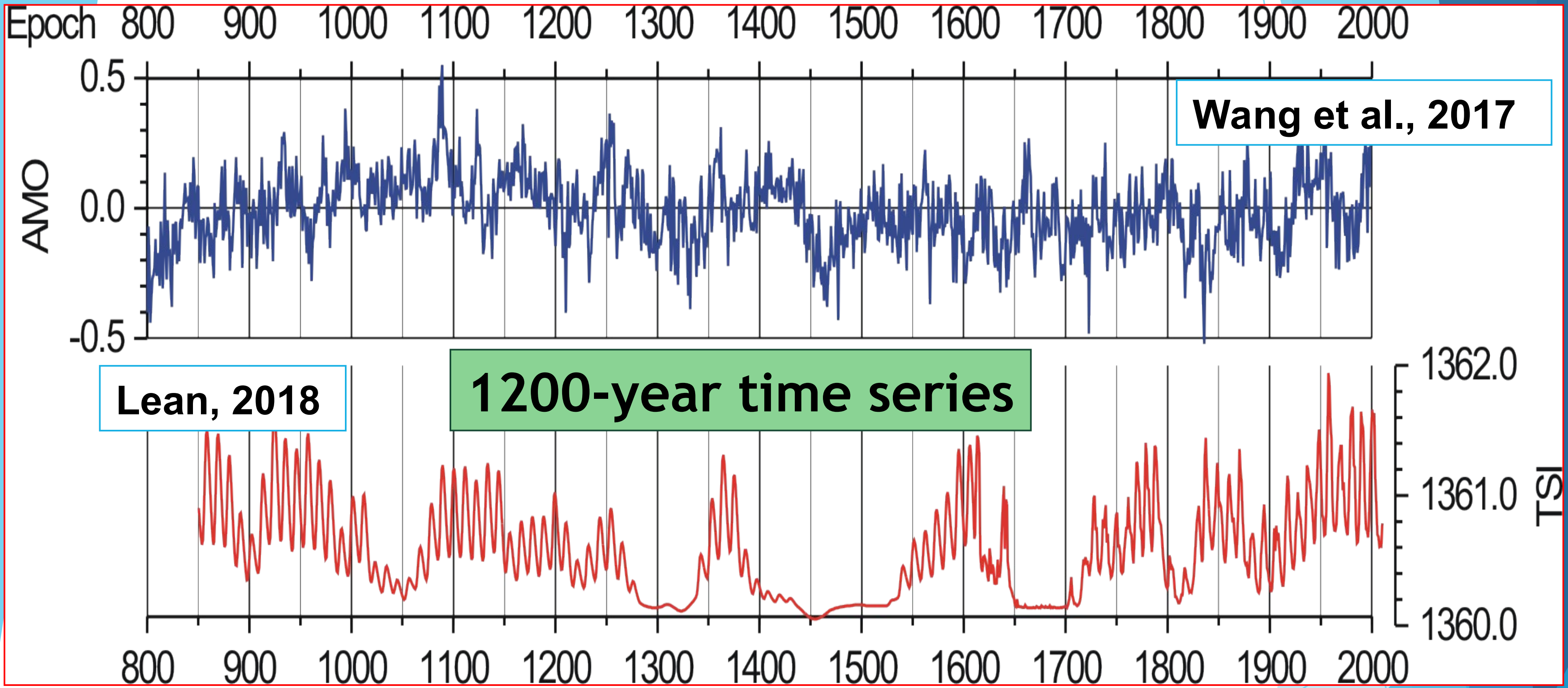
AMO and TSI data



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CONTINUOUS WAVELET METHODS

Analysis

$$W(a,b) = \langle s,\psi \rangle = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} s(t)\psi\left(\frac{t-b}{a}\right)dt$$

where $\psi(t) = e^{i2\pi f_0 t} e^{-\frac{4\ln(2)t^2}{h^2}}$ is Morlet wavelet;

Reconstruction $$s(t) = \frac{1}{C_\psi} \int_{-\infty}^{0}\int_{0}^{\infty} W(a,b)|a|^{-\frac{1}{2}}\psi\left(\frac{t-b}{a}\right)\frac{dadb}{a^2}$$

where $C_\psi = \int_{-\infty}^{\infty}\frac{|\hat{\psi}(\omega)|^2}{|\omega|}d\omega < +\infty$ is the admissibility constant depends on the chosen wavelet.

WAVELET COHERENCE

The **wavelet-squared coherency** of two time series *X* and *Y* is a ratio

$$R_n^2(s) = \frac{S(s^{-1}|W_n^{XY}(s)|^2)}{S\langle s^{-1}|W_n^X(s)|^2)\,S(s^{-1}|W_n^Y(s)|^2)}$$

where

$W_n^X(s), W_n^Y(s)$ are continuous wavelet transforms,

$S(s^{-1}|W_n^{XY}(s)|^2)$ is the absolute value squared of the smoothed cross-wavelet spectrum,

$S\langle s^{-1}|W_n^X(s)|^2)\,S(s^{-1}|W_n^Y(s)|^2)$ is product of the individual wavelet power spectra,

S is a smoothing operator,

s^{-1} convert to an energy density

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b) Partial Fourier Approximation

The AMO periodic variations, whose cycles are identical with the solar cycles, are determined by the Method of Partial Fourier Approximation (PFA). The time series of oscillations from a given frequency band are calculated as a superposition of two neighbor Fourier harmonics, whose coefficients are estimated by the Least Squares (LS) Method. The details of this method are described in (Chapanov et al., 2015). Shortly, the Partial Fourier approximation $F(t)$ of discrete data is given by

$$F(t) = f_0 + f_1(t - t_0) + \sum_{k=1}^{n} a_k \sin k \frac{2\pi}{P_0}(t - t_0) + b_k \cos k \frac{2\pi}{P_0}(t - t_0), \qquad (1)$$

This method allows a flexible and easy separation of harmonic oscillations into different frequency

$$B(t) = \sum_{k=m_1}^{m_2} a_k \sin k \frac{2\pi}{P_0}(t - t_0) + b_k \cos k \frac{2\pi}{P_0}(t - t_0), \qquad (2)$$

where the desired frequencies ω_k are limited by the bandwidth

$$\frac{2\pi m_1}{P_0} \le \omega_k \le \frac{2\pi m_2}{P_0}, \qquad (3)$$

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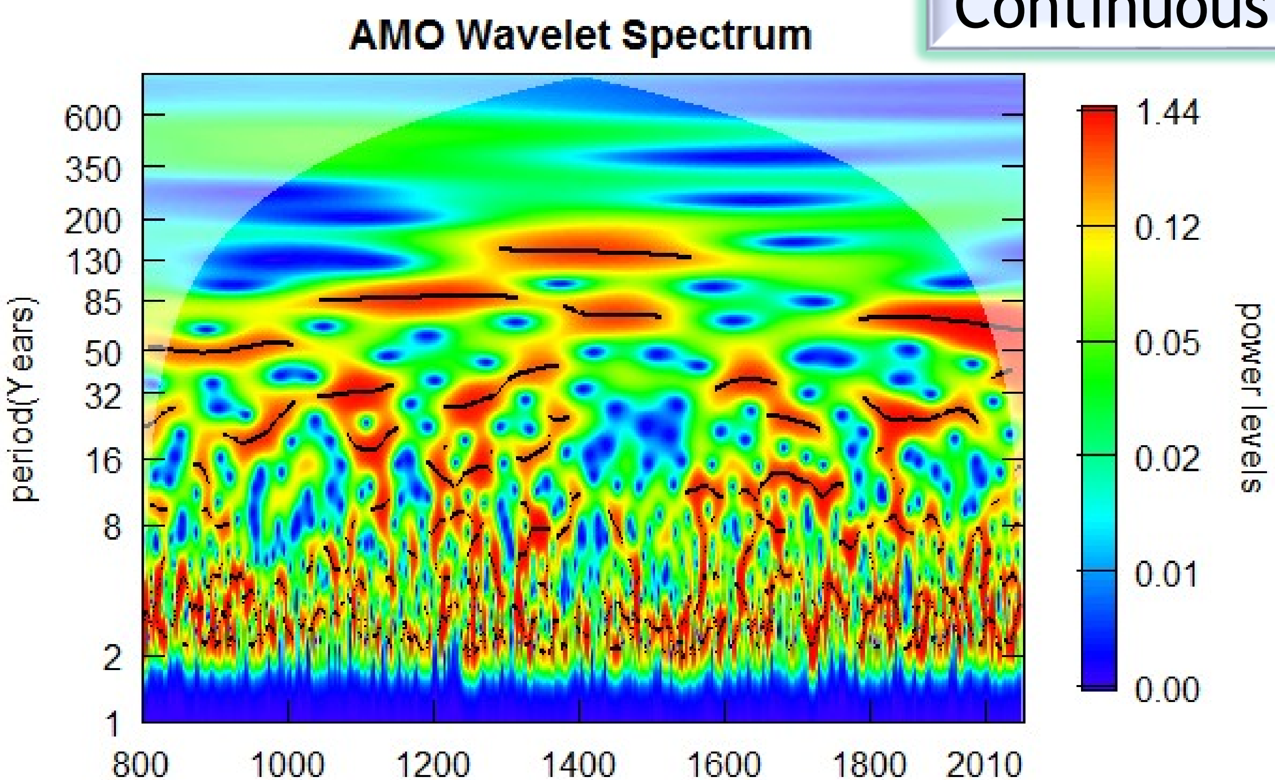
Continuous Wavelet Transform



Minor cycles of Suess - de Vries with a period from 195- to 235-year.
Variable pieces of Gleisberg cycles with periods 70-130 years .
A mode of solar rotation with periods 50-60 years.
Variable solar harmonics with periods 20-50 years.

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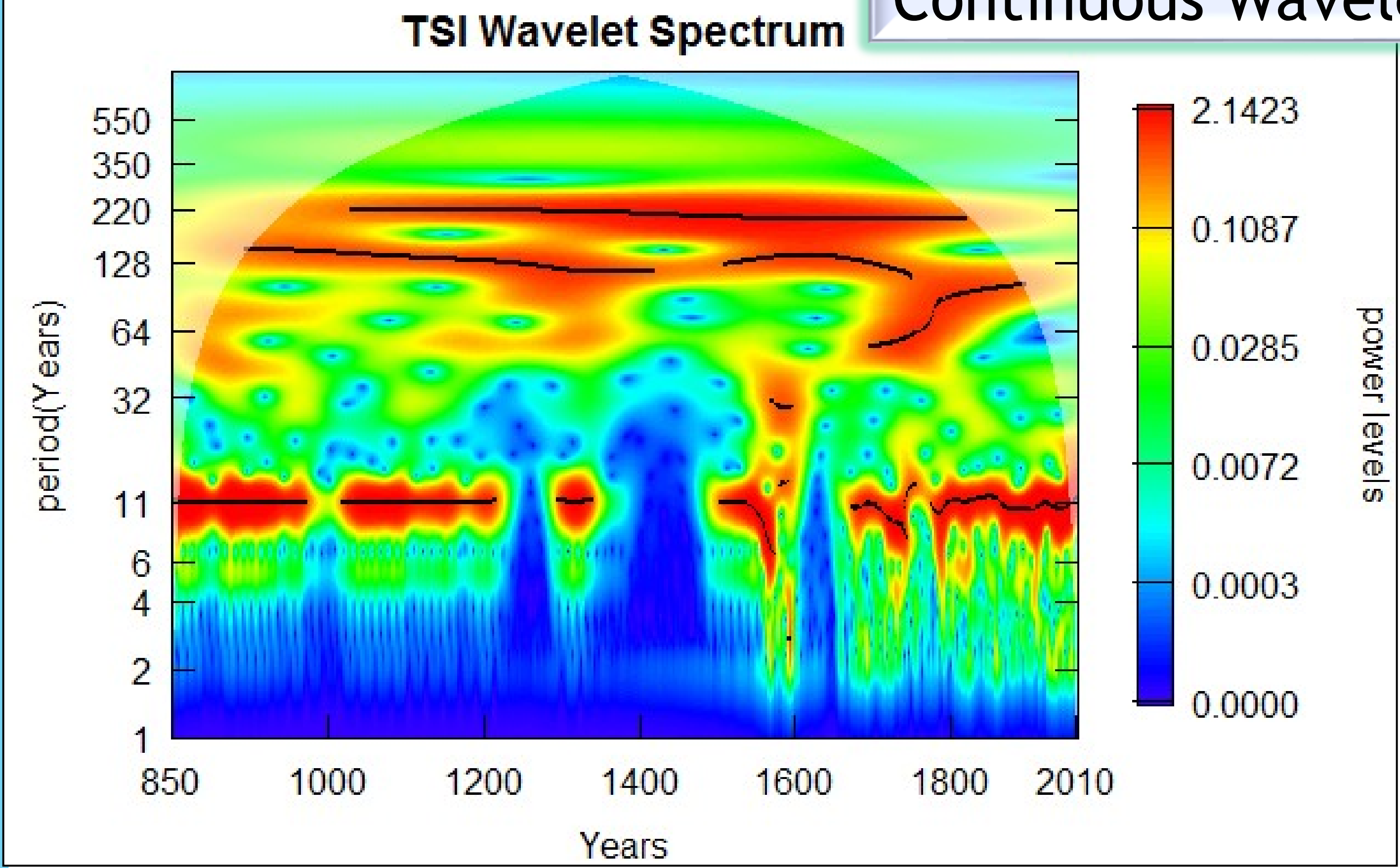
Continuous Wavelet Transform



Almost constant the Suess - de Vries cycles with a period from 195- to 235-year.
Variable Gleisberg cycles with periods 70-130 years .
Constant period of 11-year cycles for the first half of time series.

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Previous Results

Table 1. The correlation periodicities between AMO and TSI
for the period 850 – 2011 years (Chapanov, 2021)

	Correlations	
	Decadal, years	Centennial, years
1	72.4-77.3	193.2-232.8
2	64.4-68.2	144.9-165.6
3	58.0-61.0	115.9-128.8
4	48.3-54.4	

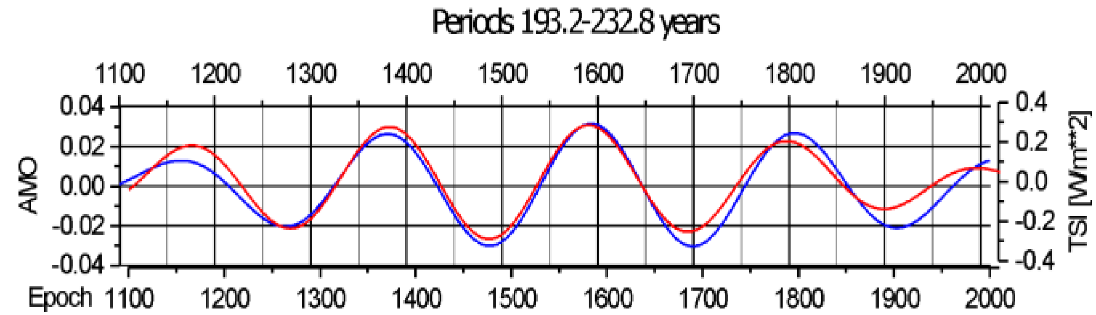


Fig.4. Centennial AMO (blue line) and TSI (red line) cycles with periods 193.2-232.8 years.

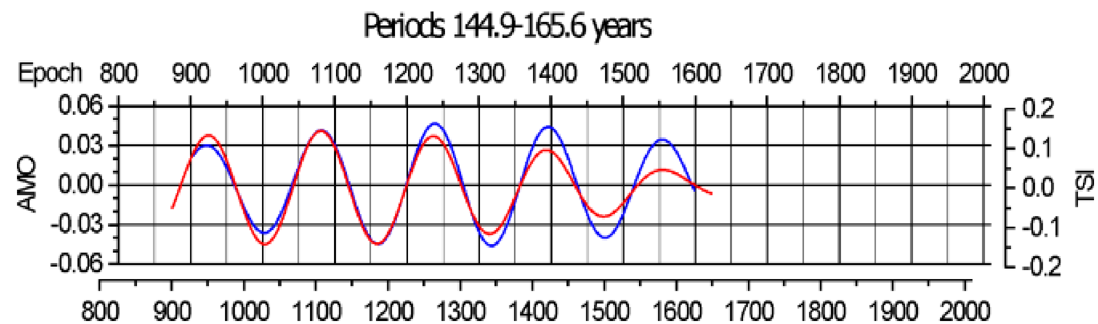


Fig.5. Centennial AMO (blue line) and TSI (red line) cycles with periods 144.9-165.6 years.

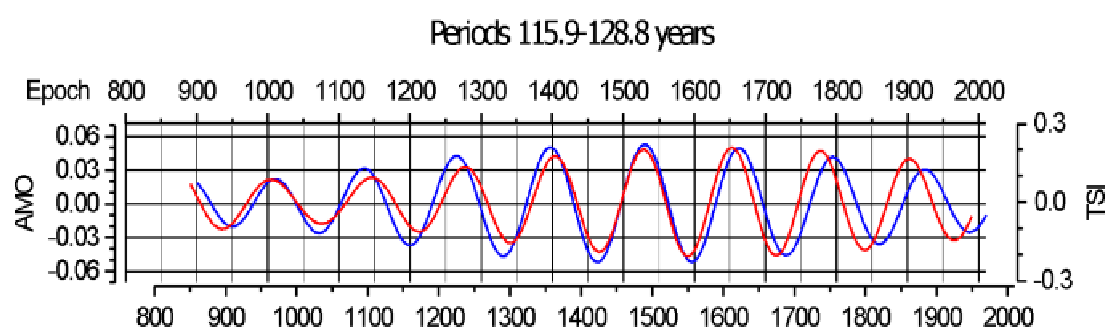


Fig.6. Centennial AMO (blue line) and TSI (red line) cycles with periods 115.9-128.8 years.

Previous Results – Common Decadal Cycles

Exact match of common solar-terrestrial cycles

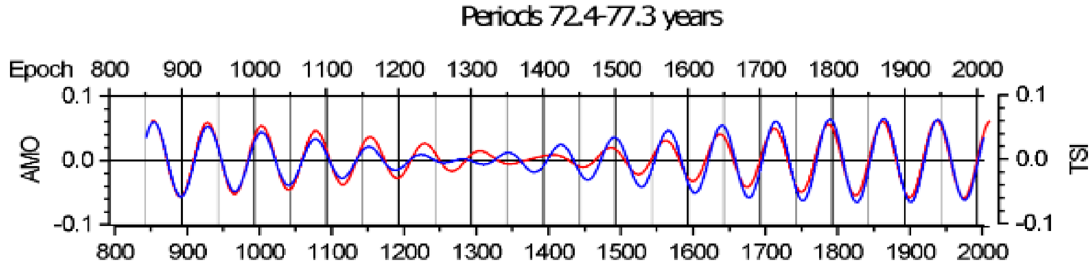


Fig.7. Decadal AMO (blue line) and TSI (red line) cycles with periods 72.4-77.3 years.

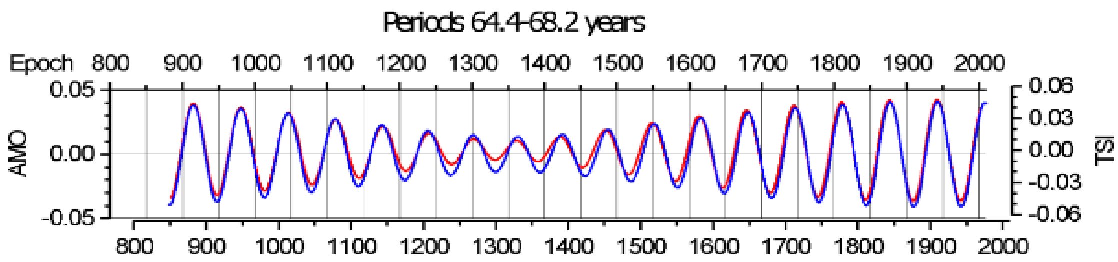


Fig.8. Decadal AMO (blue line) and TSI (red line) cycles with periods 64.4-68.2 years.

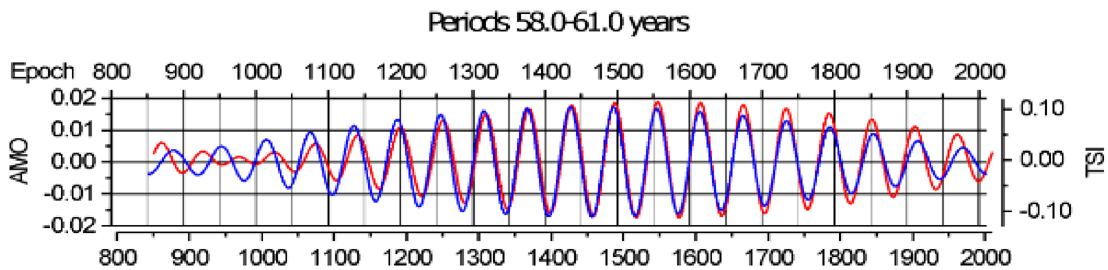


Fig.9. Decadal AMO (blue line) and TSI (red line) cycles with periods 58.0-61.0 years.

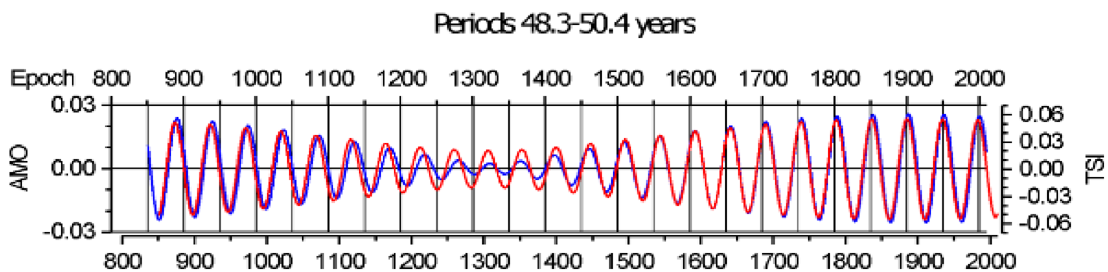
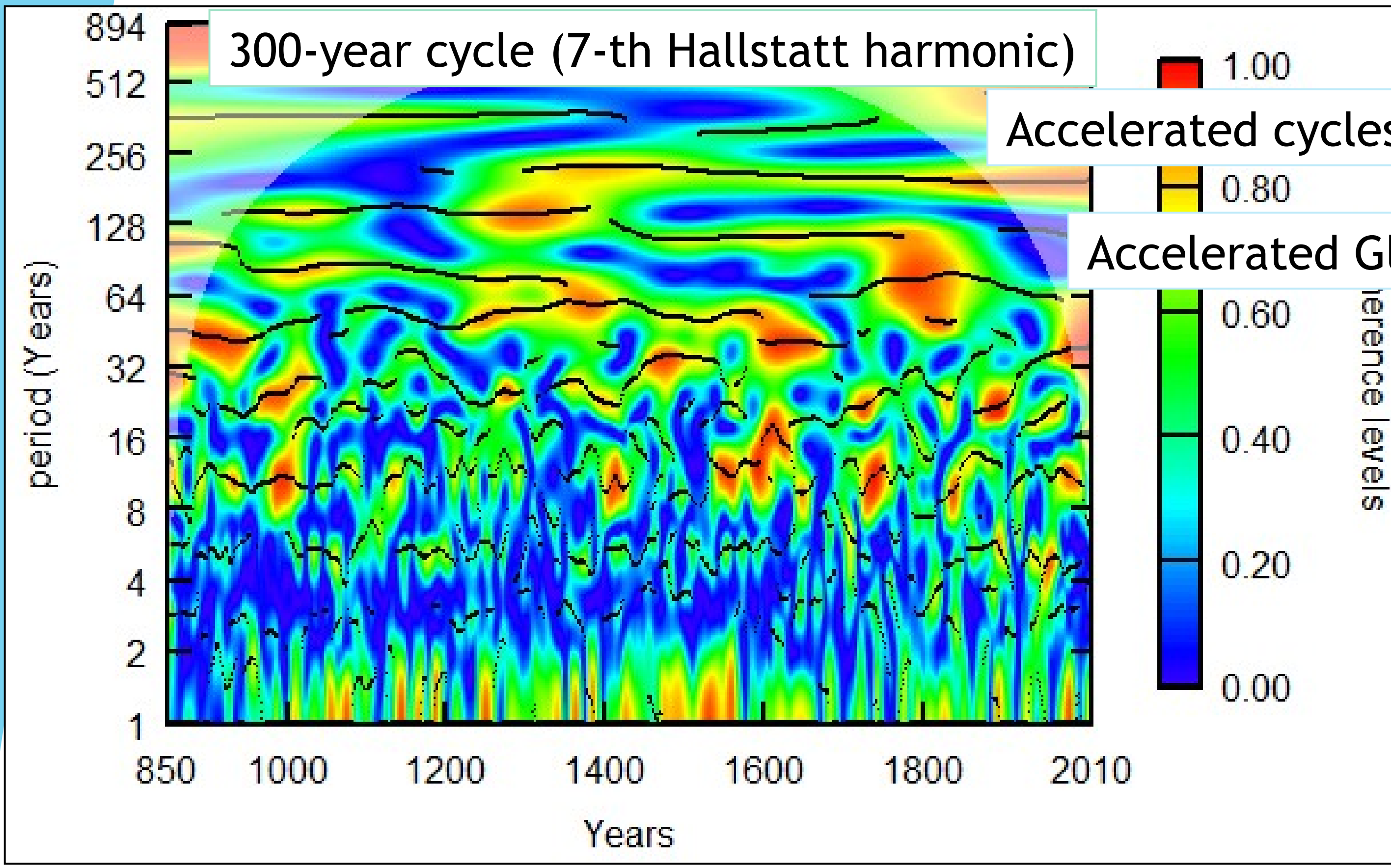


Fig.10. Decadal AMO (blue line) and TSI (red line) cycles with periods 48.3-54.4 years.

Wavelet Coherence, TSI over AMO



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Conclusions

- The wavelet transform detects time intervals with significant amplitude of oscillations and their frequency variations, while the Fourier analyzes determine all oscillations with small amplitudes.
- The wavelet transform of AMO data reveals minor Suess - de Vries cycles with periods from 195- to 235-year; variable pieces of Gleisberg cycles with periods 70-130 years; a mode of solar rotation with period 50-60 years; and variable solar harmonics with periods 20-50 years.
- The wavelet transform of TSI data reveals almost constant Suess - de Vries cycles with a period from 195- to 235-year; variable Gleisberg cycles; and constant period of 11-year cycles for the first half of time series.
- The AMO-TSI coherence is significant for oscillations close to 7-th harmonic of 2300-year Hallstatt solar cycle with 300-year period; accelerated cycles of Suess - de Vries and accelerated Gleisberg cycles, whose frequencies slightly increase, while the oscillations with periods below 50 years decrease their frequencies.
- The application of both Fourier and wavelet analyzes may significant improve interdisciplinary research

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