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Decadal NAO Oscillations Excited by TSI Cycles

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Abstract.

The solar activity strongly affects climate cycles by the Total Solar Irradiance (TSI) variations. The common solar and climate cycles are studied by means of multi-decadal winter North Atlantic Oscillation (NAO) reconstruction for the period 1049-1995. The winter NAO variations are based on a speleothem-based precipitation proxy from Scotland and a tree-ring based drought proxy from Morocco and reflect precipitation regimes over the Millennium. A part of this reconstruction is compared with the TSI variations after 1610 in different decadal frequency bands. The time series are analyzed by the Method of Partial Fourier Approximation (PFA), and common cycles of TSI and NAO are determined in 12 frequency bands with periods between 8.5 and 50yr.

Introduction

The solar activity affects various processes on Earth surface, oceans and atmosphere. The solar cycles are connected with significant TSI variations, whose direct effect on the Earth is visible as climate and weather change. The shape of 11-year TSI cycles is not sinusoidal, so the solar-terrestrial influences are driven by various harmonics with interannual, decadal and centennial periodicity.

The North Atlantic Oscillation is a regional process, whose weather and climatic variations have long been detected and studied. The NAO is a complex climatic phenomenon with a wide range of periodicities in meteorological parameters as temperature and pressure fields, atmospheric precipitation, tropical cyclone activity, wind direction, and wind strength. The NAO is the dominant mode for winter climate variability over a vast region that extends from central North America to Europe and also involves a considerable part of northern Asia. The NAO is part of the Arctic Oscillations and is also geographically related to the Atlantic Multidecadal Oscillation (AMO), which is caused by variations in the North Atlantic surface temperature.

In order to predict climatic changes in this region, it is necessary to study the spatial and temporal dynamics of NAO, and to determine the causes of its external excitation. Significant influence of TSI on long-term NAO variations with periodicities above 50 years is determined in (Gorshkov and Chapanov, 2020). Here the TSI influence on NAO cycles with periods below 50 years is studied.

Data

The TSI and NAO data are presented in Fig.1. The estimated solar irradiances for the last 400 years are based on the NRLTSI2 historical TSI reconstruction model by J. Lean (Fig. 1, bold line), the last version in (Coddington at al. 2016). The Winter NAO reconstruction (Fig. 1, dashed line) is based on decadal scale variations in a speleothem precipitation proxy from Scotland and a tree-ring drought proxy from Morocco. It reflects quasi-regular occurrences of contrasting precipitation regimes over the Millennium. These proxy records are located centrally in the opposing poles of NAO driven precipitation regimes (Trouet et al., 2009).

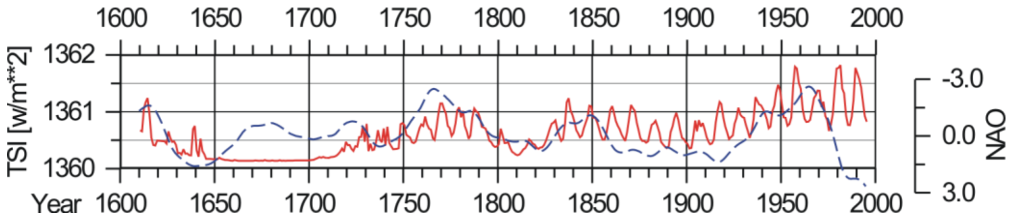

Fig.1. Time series of TSI (solid red line) and NAO (dashed blue line).

Methods

The time series spectra are determined by the well-known Fast Fourier Transform (FFT). The periodical variations are derived from the data by means of partial Fourier approximation based on the Least-Squares estimation of Fourier coefficients. The Partial Fourier approximation $F(t)$ of time series is given by

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

where P_0 is the period of the first harmonic, t_0 - the mean epoch of observations, f_0, f_1, a_k and b_k are unknown coefficients and n is the number of harmonics of the partial sum, which covers all oscillations with periods between P_0/n and P_0. The application of the LS estimation of Fourier coefficients needs at least $2n+2$ observations, so the number of harmonics n is chosen significantly smaller than the number N of sampled data f_i. The small number of harmonics n yields to LS estimation of the coefficient errors. This estimation is the first essential difference with the classical Fourier approximation. The second difference is the arbitrary choice of the period of first harmonic P_0, instead of the observational time span, so the estimated frequencies may cover the desired set of real oscillations. This method allows a flexible and easy separation of harmonic oscillations into different frequency bands by the formula

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

where the desired frequencies ω_k are limited by the bandwidth

$$\frac{2\pi m_1}{P_0} \le \omega_k \le \frac{2\pi m_2}{P_0}, \tag{3}$$

After estimating the Fourier coefficients, it is possible to identify a narrow frequency zone presenting significant amplitude, and defining a given cycle. Then this cycle can be reconstructed in time domain as the partial sum limited to the corresponding frequency bandwidth. Doing this for terrestrial and solar time series, we shall identify their respective cycles, isolate and compare the common ones.

This method provides Least Squares estimate of 150 harmonically coefficients with average accuracy of about 8mW/m^2 for TSI; and 0.002 for NAO.

Results

a) Time series spectra

The time series spectra of NAO and TSI are determined by the Fast Fourier Transform. The NAO and TSI spectra are almost coherent for periods between 12 and 200 years, so it is possible to find a lot of narrow frequency bands with common decadal and centennial TSI and NAO cycles.

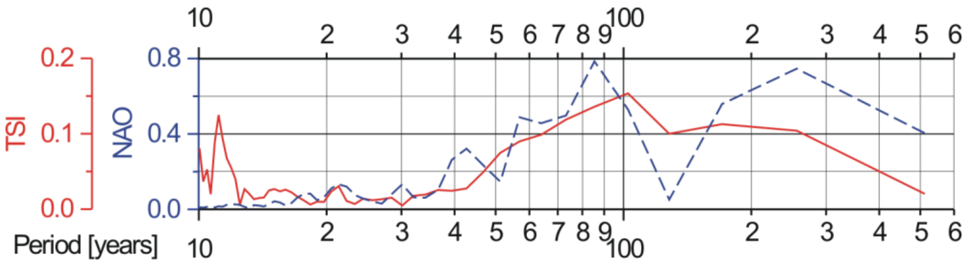

Fig.2. Spectra of NAO and TSI time series, determined by the FFT.

b) TSI influence on NAO cycles

The TSI influence on NAO variations is detected in 12 narrow frequency bands with interannual and decadal cycles with periods below 50 years (Figs. 3-6). These frequency bands are divided into 3 groups with periodicities 30 - 50yr; 20 - 30yr; and 8-20yr. The common TSI and NAO cycles from the first group of periodicities are shown in Fig.3. Excellent agreement exists between TSI and NAO cycles with periods 42.6 – 47.9 years (Fig.3, a), where is the essential 45-year solar cycle, associated with the N-S solar asymmetry. The other two bands expose relatively good agreement between TSI and NAO variations, where a phase reverse occurs in 1680-1770.

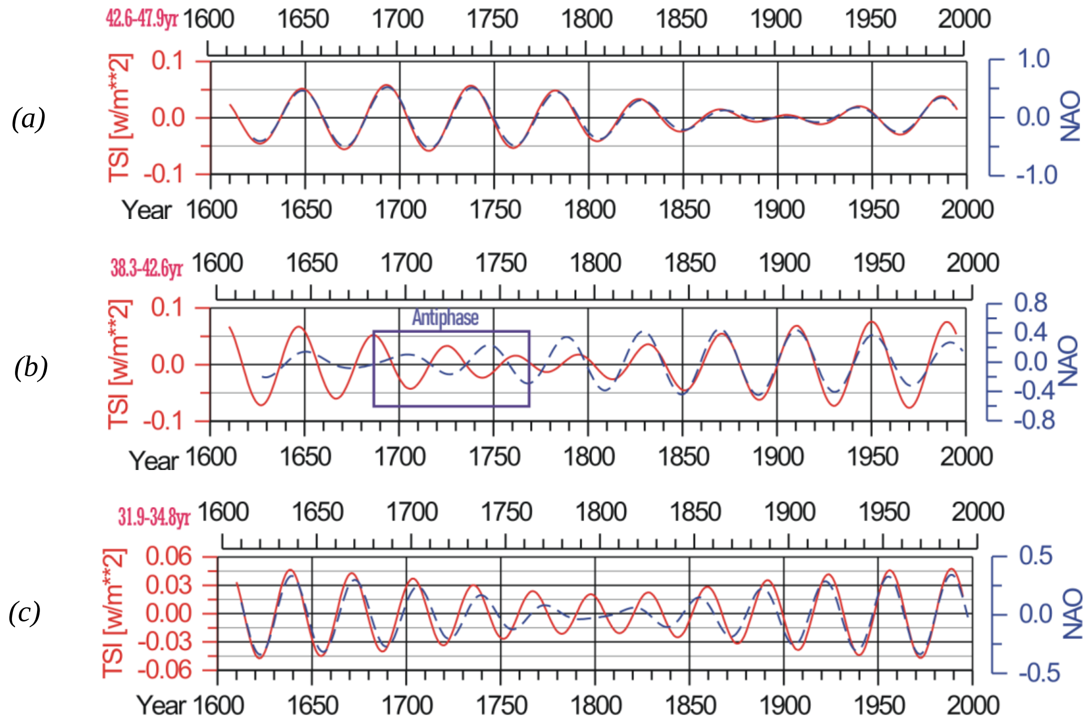

Fig.3. Common TSI and NAO cycles with periods from bands: 42.6 - 47.9 years (a); 38.3 - 42.6 years (b); and 31.9 - 34.8 years (c).

The second group of frequency bands are presented in Fig.4. It covers periodicities between 29.5 – 31.9; 27.9 – 29.5; and 25.5 – 27.4 years. The agreement between the solar and climate cycles is relatively good, with two phase reverses.

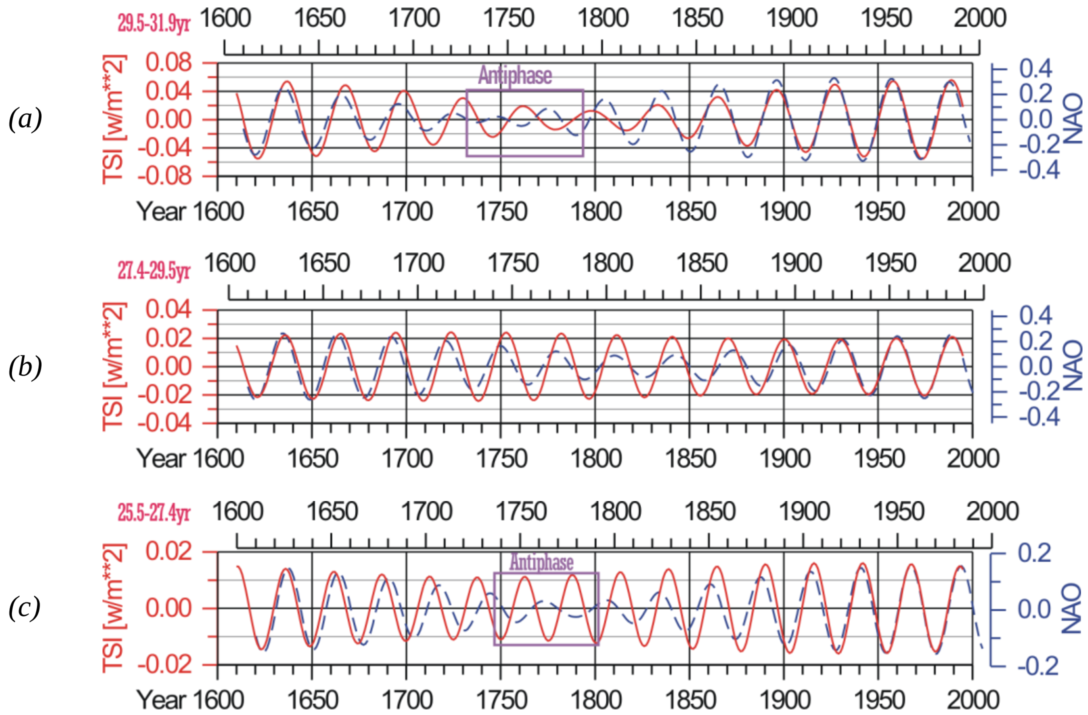

Fig.4. Common TSI and NAO cycles with periods from bands: 29.5 - 31.9 years (a); 27.9 - 29.5 years (b); and 25.5 – 27.4 years (c).

The third group of TSI-NAO periodicities consists of 6 frequency bands, shown in Figs. 5 and 6. These frequency bands cover periodicities between 16.7 – 17.4; 14.2 – 14.7; 13.2 – 13.7, 12.4 – 12.8; 10.6 – 11.2; and 8.5 – 8.7 years. The TSI and NAO oscillations have common cycles with very good agreement for these periodicities with exception of 11-year Schwabe cycles, whose oscillations agree in 1850-2000 only (Fig.6, b).

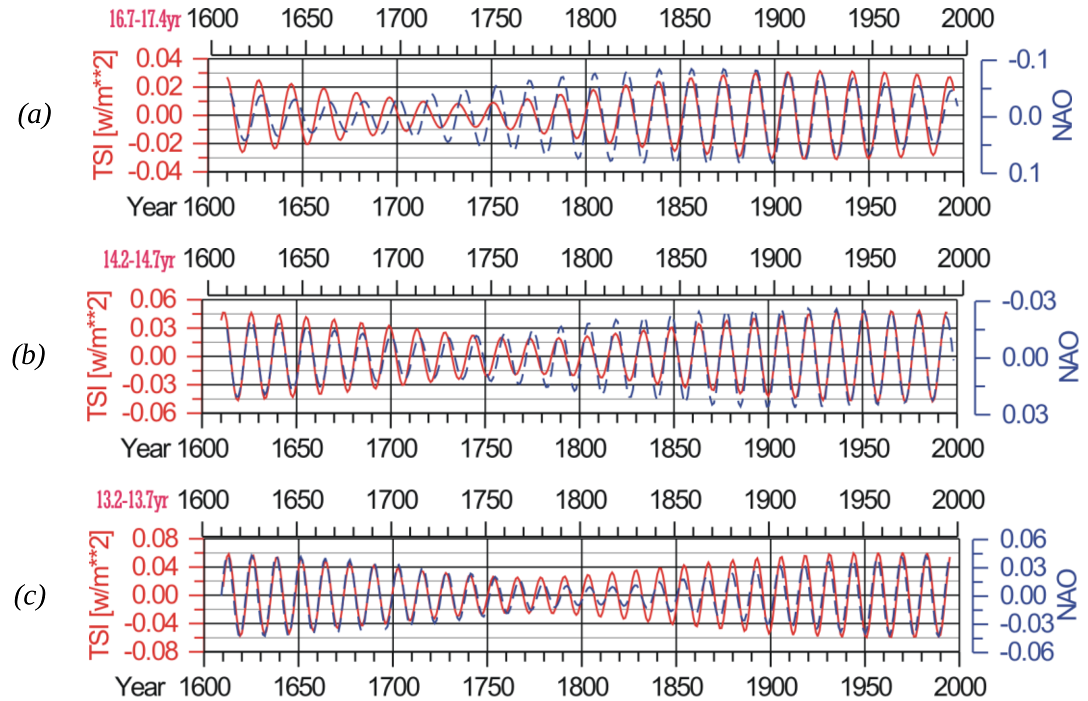

Fig.5. Common TSI and NAO cycles with periods from bands: 16.7 – 17.4 years (a); 14.2 – 14.7 years (b); and 13.2 – 13.7 years (c).

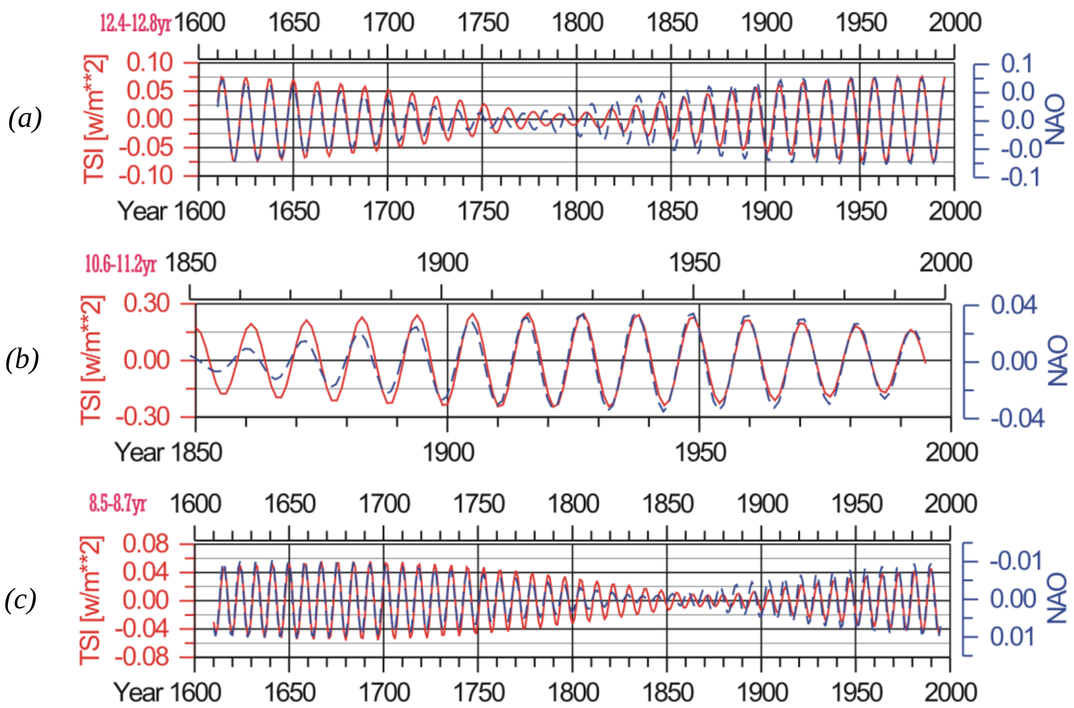

Fig.6. Common TSI and NAO cycles with periods from bands: 12.4 – 12.8 years (a); 10.6 – 11.2 years (b); and 8.5 – 8.7 years (c).

Conclusions

The common TSI and NAO cycles are determined by the Method of Partial Fourier Approximation. This method provides Least Squares estimate of the harmonically coefficients with average accuracy around 8mW/m^2 for TSI; and 0.002 for NAO. The common cycles are shown in Figs. 3-6, where the solid lines represent TSI oscillations; and the dashed lines represent the NAO cycles. Very good agreement between TSI and NAO cycles exists in 12 interannual and decadal frequency bands. The common decadal oscillations are represented in bands with decadal periods 42.6 - 47.9yr, 38.3 - 42.6yr, 31.9 - 34.8yr, 29.5 – 31.9yr; 27.9 – 29.5yr, 25.5-34.8yr; 16.7-17.4yr, 14.2-14.7yr, 13.2-13.7yr and 12.4-12.8yr. The common interannual cycles are determine in a single band with periods 8.5-8.7yr. The most of these common cycles have positive correlation and 3 of them – negative correlation.

The 11-year Schwabe oscillations are presented in frequency band with periods 10.6-11.2yr. Good agreement between 11-year TSI and NAO cycles exists in time interval 1850-1995 only (Fig.6, b). Before 1850 the TSI and NAO oscillation have different time lag and significant discrepancy of amplitude variations, so these are possible reasons of negative results about solar-climate interconnection in (van Oldenborgh et al., 2013)

The NAO is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe and much into Northern Asia. The knowledge of common solar and NAO cycles may help better understanding of winter climate variability in North America and Europe. On the base of existing deep solar minimum, it is possible to predict high positive values of NAO index in next decade and corresponding windstorms and wet winters in Europe.

Acknowledgements

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