

Atlantic Multidecadal Oscillation Driven by Solar Harmonics

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Abstract.

The oscillations of climatic parameters of North Atlantic Ocean play important role in various events in North America and Europe. Several climatic indices are associated with these oscillations. The long terms of Atlantic temperature anomalies are presented by Atlantic Multidecadal Oscillation. Its time series is analyzed by means of the Method of Partial Fourier Oscillations. The cycles of AMO in narrow frequency bands are compared with corresponding oscillations of Total Solar Irradiance (TSI). Very good agreement exists between interannual and decadal cycles of AMO and TSI.

Introduction

The aim of this work is to determine influence of solar harmonics on Atlantic Sea Surface Temperature (SST). The Atlantic Multidecadal Oscillation (AMO), also known as Atlantic Multidecadal Variability (AMV), is the variability of the sea surface temperature (SST) of the North Atlantic Ocean on the timescale of several decades. The AMO is correlated to air temperatures and rainfall over much of the Northern Hemisphere, in particular in the summer climate in North America and Europe (Ghosh et al., 2016; Zampieri et al., 2017). Rainfall patterns are affected in North Eastern Brazilian and African Sahel. It is also associated with changes in the frequency of North American droughts and is reflected in the frequency of severe Atlantic hurricane activity (Trenberth et al., 2005). Climate models suggest that a warm phase of the AMO strengthens the summer rainfall over India and Sahel and the North Atlantic tropical cyclone activity (Zhang and Delworth, 2006).

The solar activity affects all Earth system and excites their periodic variations with the essential solar frequencies and their harmonics. Solar irradiance is Earth's primary energy input. It establishes the thermal and dynamical structure of the terrestrial environment and is the primary external cause of terrestrial variability. The specification of solar irradiance over multiple centuries is requisite input for numerical simulations of climate variability prior to the industrial epoch that provide a baseline against which to evaluate contemporary anthropogenic influences.

One of the main reason of Sea Surface Temperature (SST) variation is the direct influence of TSI on the ocean. The common analyze and comparison of TSI and AMO oscillations in different narrow frequency bands may significantly improve our knowledge of solar-terrestrial influences and contribute to more precise climatic models and forecasts.

Data and Methods

a) AMO and TSI time series

Wang et al. (2017) reconstructed Summer (during May to September) Atlantic Multidecadal Variability (AMV) time series by applying the principal component regression method to 46 annually-resolved terrestrial proxy records from the North Atlantic region (Fig.1). The internal variability component of Atlantic Multidecadal Variability (i.e., Atlantic Multidecadal Oscillation; AMO) was estimated by empirically removing externally-forced variations at multidecadal (> 30 years) timescales. Data are reported as sea surface temperature anomalies with respect to 1856-1973. Fig.1 demonstrates map of data sources of AMO variations for the last 1200 years, according (Wang et al., 2017). The reconstructed time series of AMO variations are shown in Fig. 2. Lean (2018) creates TSI time series for the period 850-2010 (Fig. 2).

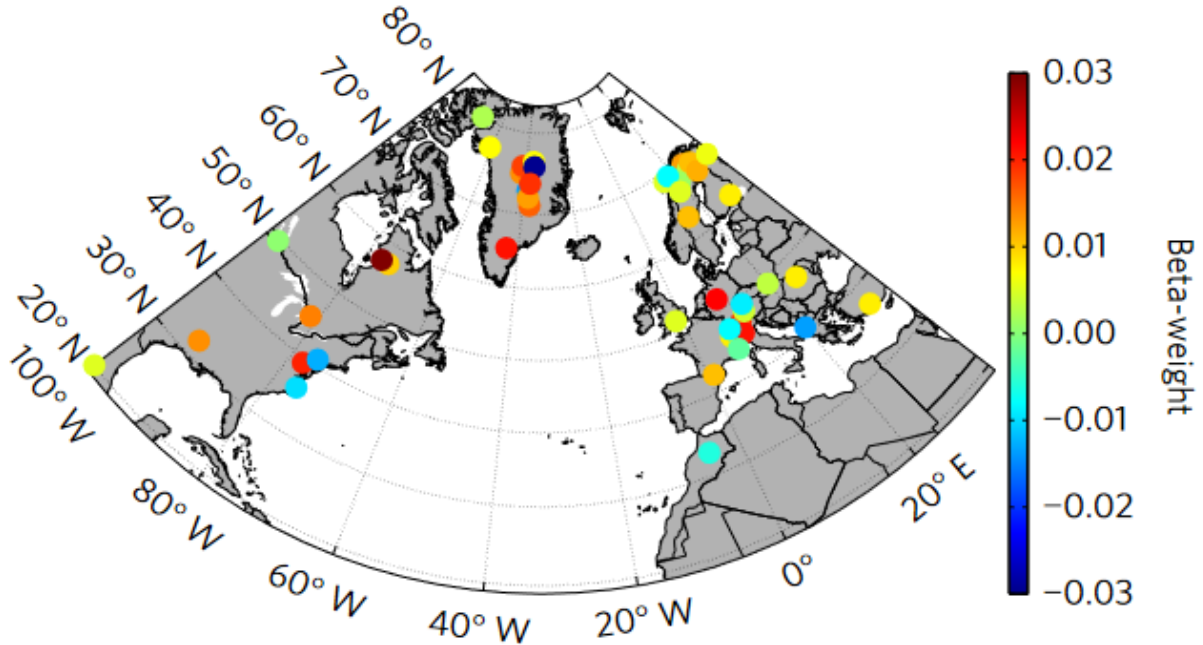


Fig.1. Region 20N-80N; 100W-35E of AMO data determination, according Wang et al. (2017).

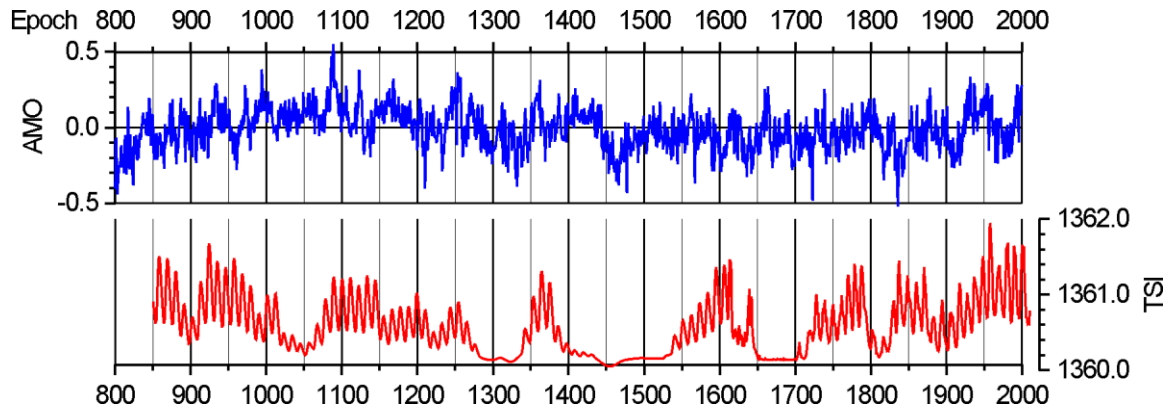


Fig.2. AMO time series (top, blue line) and TSI time series (bottom, red line).

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

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

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 important difference with the classical Fourier approximation. The other difference is the possibility of 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

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

where the desired frequencies ω_k are limited by the bandwidth

$$\frac{2\pi m_1}{P_0} \leq \omega_k \leq \frac{2\pi m_2}{P_0}, \quad (3)$$

After estimating the Fourier coefficients, it is possible to identify a narrow frequency band 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 common cycles.

The used time series of AMO and TSI long-term variations cover 1161-year overlapped time interval for the period 850.0 – 2011.0. The PFA performs estimation of 150 harmonics with the accuracy better than 0.006 for AMO and 5 mW/m² for TSI coefficients.

Results

a) FFT spectra

The AMO and TSI spectra are determined by the Fast Fourier Transform (FFT). Their spectra have common centennial oscillations with periods 80-200 years and some decadal cycles, whose periodicity lays above 30 years (Fig. 3).

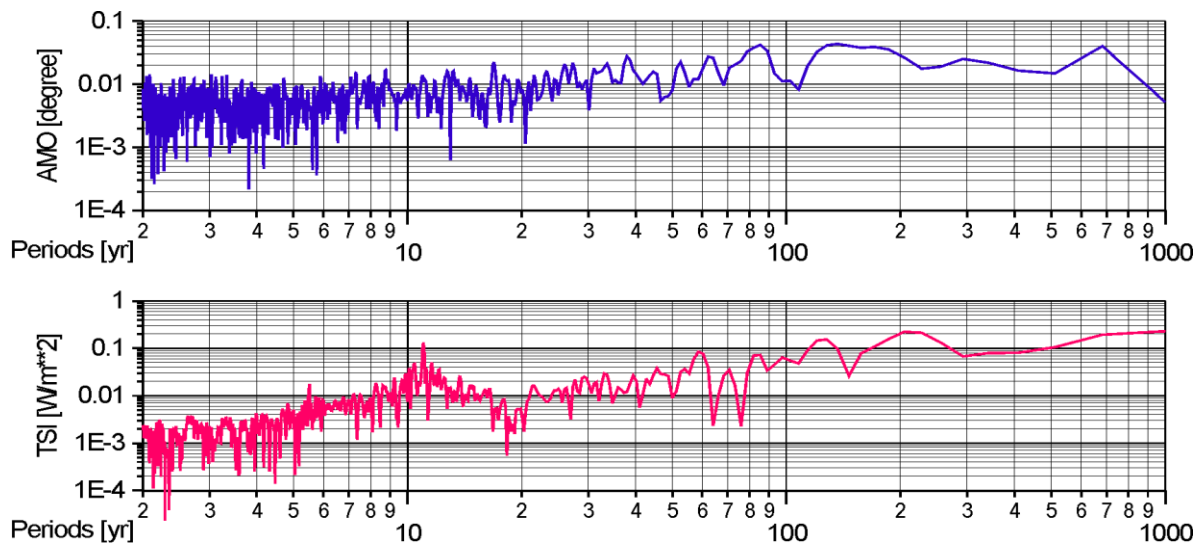


Fig.3. FFT spectra of AMO and TSI time series.

b) Solar influence on centennial AMO cycles

The solar influences on centennial AMO oscillations are presented in 3 bands, whose periodicity is between 116 and 233 years (Figs. 4-6). The TSI and AMO variations with periods between 193.2 and 232.8 years are shown in Fig. 4. The agreement between time series with these oscillation is excellent with a high correlation between them for the time interval 1100-2010. Before 1100 these oscillations are out of phase. Next partial correlation between TSI and AMO cycles are detected for periodicity 144.9-165.6 years for time interval 900-1600 (Fig. 5). Only common cycles with periods 115.9-128.8 years cover the whole 1100-year time interval 900-2000 (Fig. 6).

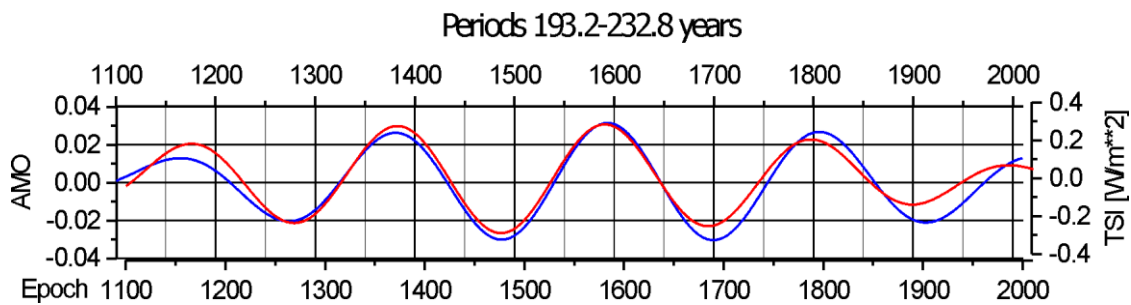


Fig.4. Centennial AMO (blue line) and TSI (red line) cycles with periods 193.2-232.8 years.

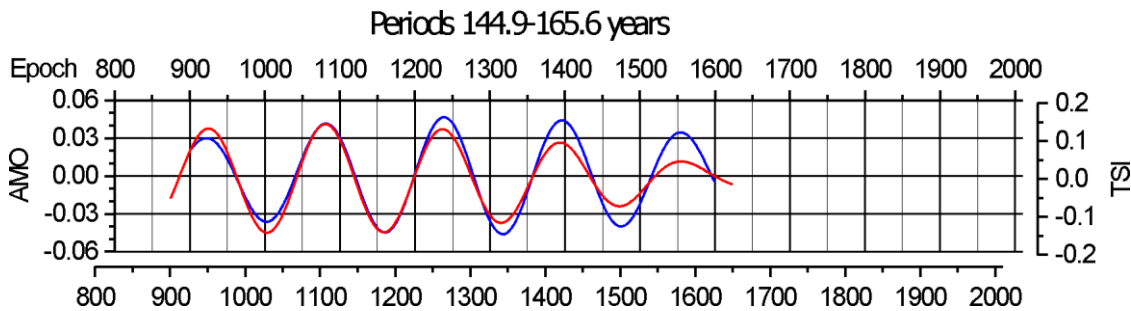


Fig.5. Centennial AMO (blue line) and TSI (red line) cycles with periods 144.9-165.6 years.

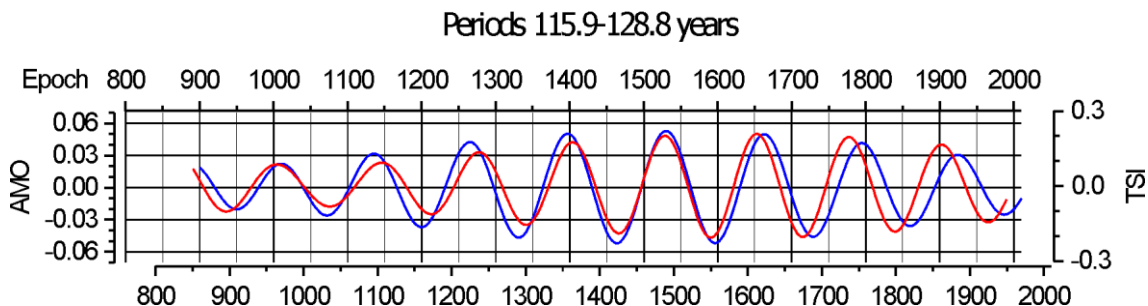


Fig.6. Centennial AMO (blue line) and TSI (red line) cycles with periods 115.9-128.8 years.

c) Solar influence on decadal AMO cycles

The solar influence on decadal AMO oscillations are detected in 4 narrow frequency bands with periodicities 48.3-72.4 years (Figs. 7-10). The decadal TSI and AMO oscillations have excellent agreement and their common cycles may serve as a good base of climate modelling and forecast improvements.

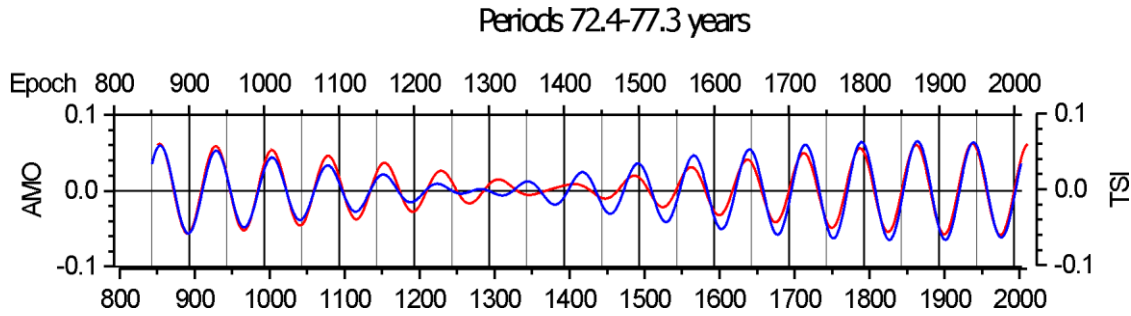


Fig.7. Decadal AMO (blue line) and TSI (red line) cycles with periods 72.4-77.3 years.

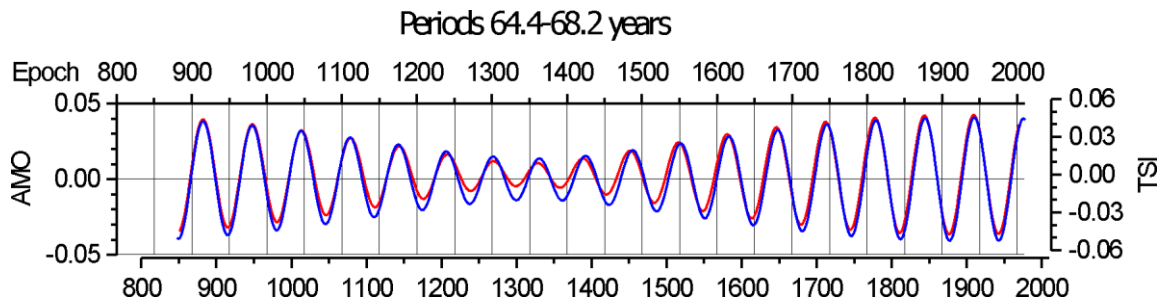


Fig.8. Decadal AMO (blue line) and TSI (red line) cycles with periods 64.4-68.2 years.

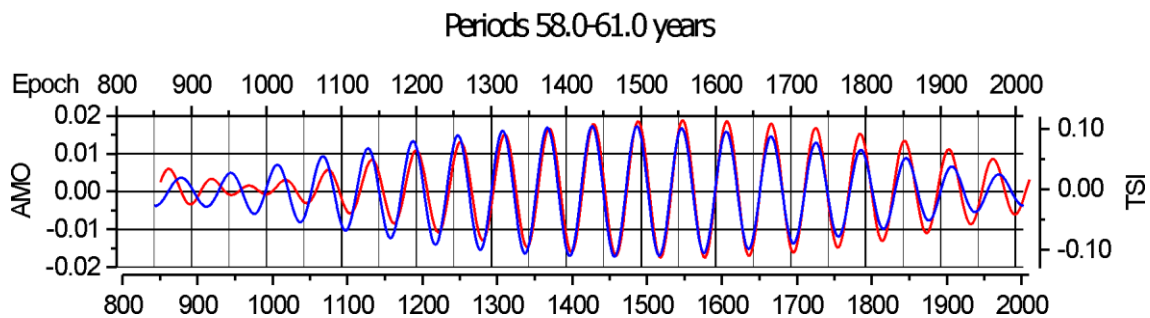


Fig.9. Decadal AMO (blue line) and TSI (red line) cycles with periods 58.0-61.0 years.

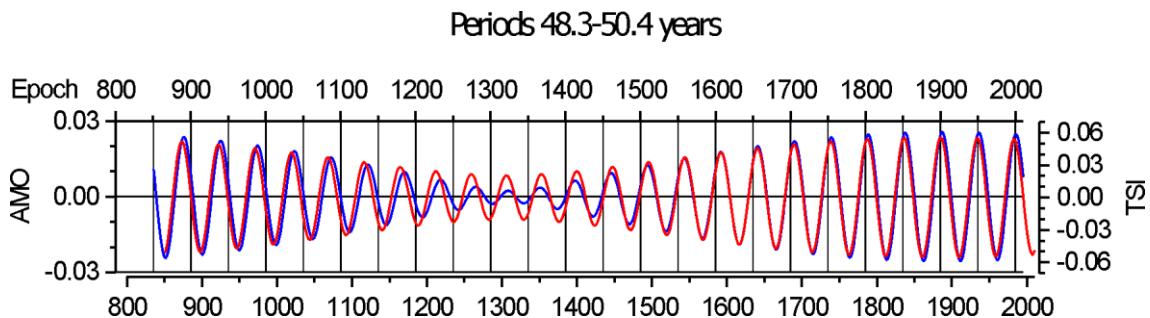


Fig.10. Decadal AMO (blue line) and TSI (red line) cycles with periods 48.3-54.4 years.

Conclusions

The new largest time series of AMO and TSI variations, whose time span cover more than 11 centuries, give good opportunity of better understanding the solar-terrestrial influences in the area of climate variations and climate change. The analyze of AMO and TSI time series by means of the Method of Partial Fourier Approximation determine 3 centennial and 4 decadal

narrow frequency bands, where the solar and terrestrial cycles have good agreement. The common TSI and AMO cycles cover periodicities between 48 and 233 years. They may serve as a good instrument of climate modelling and long-term forecasts.

Acknowledgements

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