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THE NAO – WINTER INDEX VARIABILITY 1820-2100

The winter is coming

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1 INTRODUCTION

The North Atlantic Oscillation (NAO) is a weather phenomenon in the North Atlantic Ocean of fluctuations in the difference of atmospheric pressure at sea level (SLP) between the Icelandic low and the Azores high. Through fluctuations in the strength of the Icelandic low and the Azores high, it controls the strength and direction of westerly winds and location of storm tracks across the North Atlantic. [1]

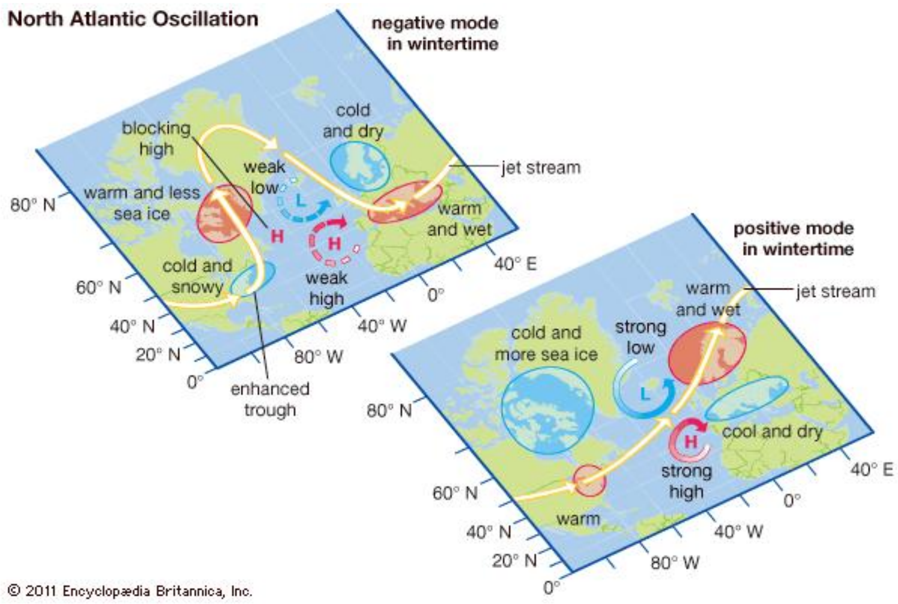

Figure 1. The North Atlantic Oscillation

The winter (December thru March) station-based index of the NAO is based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland since 1864. Positive values of the NAO index are typically associated with stronger-than-average westerlies over the middle latitudes, more intense weather systems over the North Atlantic and wetter/milder weather over western Europe. Monthly, seasonal and annual indices using slightly different data sources for the southern station are also available [2].

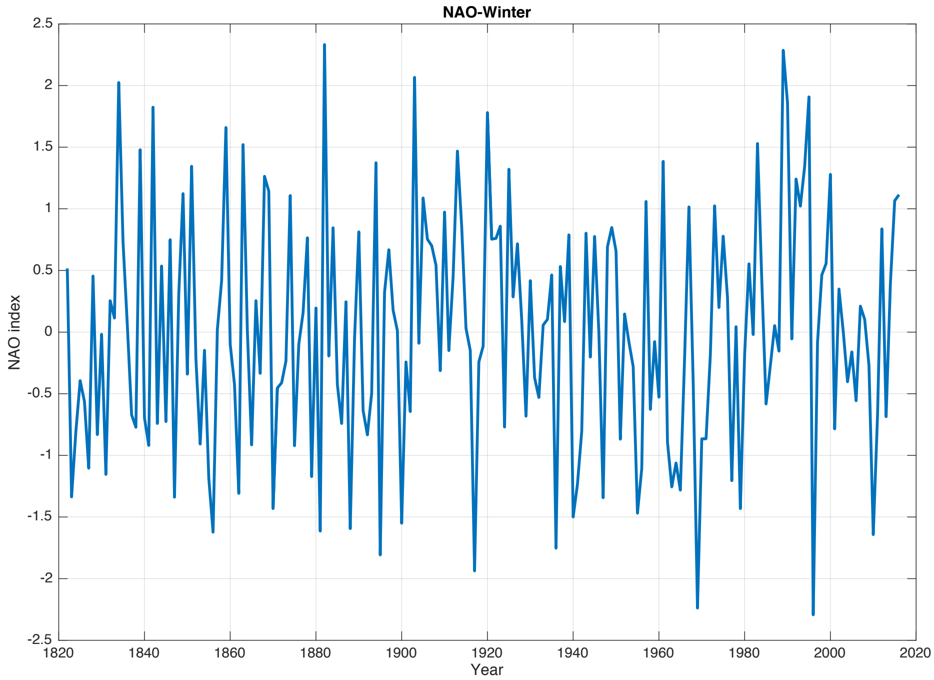

Figure 2. The NAO-winter index data series from 1822 to 2016.

Figure 2 shows the annual NAO winter index from 1822 to 2016 [4]. The NAO winter index is computed by (December (n-1)+January (n)+February (n) + Mars (n))/4. The NAO winter index looks random and has large fluctuation from one year to another. A wavelet spectrum analysis of the data series may show periods trends in the data series

The cause of NAO oscillation is not well understood. Izhevskii (1961, 1964) introduced a system view of interacting processes between the hydrosphere, the atmosphere, and the biosphere. He argued that the heat in the ocean is a non-homogenous flow from a warm equator to the cold pole. This flow of heat in the ocean influences atmospheric processes. Atmospheric processes are reflected in the North Atlantic Oscillation (NAO), and the NAO influences weather and climate in and around the Atlantic. A strongly positive NAO winter index will lead to stronger winds and warmer air in winter.

A positive trend from 1960 increased winter temperature in the northeastern Atlantic and the North Sea, a trend shift that has led to speculation about more fundamental climate change, connected to an Arctic oscillation. The gravity force from the 18.6-year lunar nodal cycle influences polar position and, very likely, the circulating water in the Arctic Ocean. A stationary polar-position cycle forces the Arctic Ocean, and introduces an Arctic oscillation that interacts with the Atlantic, Arctic ice extent, and Arctic atmospheric conditions. The force from the lunar nodal spectrum is transformed into a spectrum of oscillating water circulation in which some harmonic cycles are preserved by resonance. A continuous supply of movement energy is distributed throughout circulating water in the Atlantic Ocean. In this circulating process, the Arctic Ocean and the lunar nodal tide have an influence on the Atlantic Ocean inflow to the Barents Sea, as well as fluctuations in water temperature, Arctic ice extent, air temperature, and the North Atlantic Oscillation [3].

A wavelet analysis of NAO winter index has estimated dominant-wavelet cycles of 6, 18, and 74 years, close to the lunar periods [18.61/3=6.2, 18.61, 18.61*4=74.4] yr. The 74-year cycle has a -0 trend shifts in [1825, 1860, 1895, 1935, 1970], minima in [1880, 1955], maxima in [1845, 1918, 1995]. The 18-year NAO index cycle is at a maximum in the same years as the 18-year cycle of Barents Sea ice extent is at its minimum. This confirms that there is a warmer winter when there is a reduction in Arctic ice cover. The 18-year cycle has a phase reversal at about [1840, 1890, 1950]. Then, the phase reversal is related to turning points from the 74-year cycle [3].

This study is based on a new the wavelet analysis of the NAO-winter index. This time there is 10 years more of data, better analysis methods and more data Arctic data series.

2. THE NAO INDEX VARIABILITY

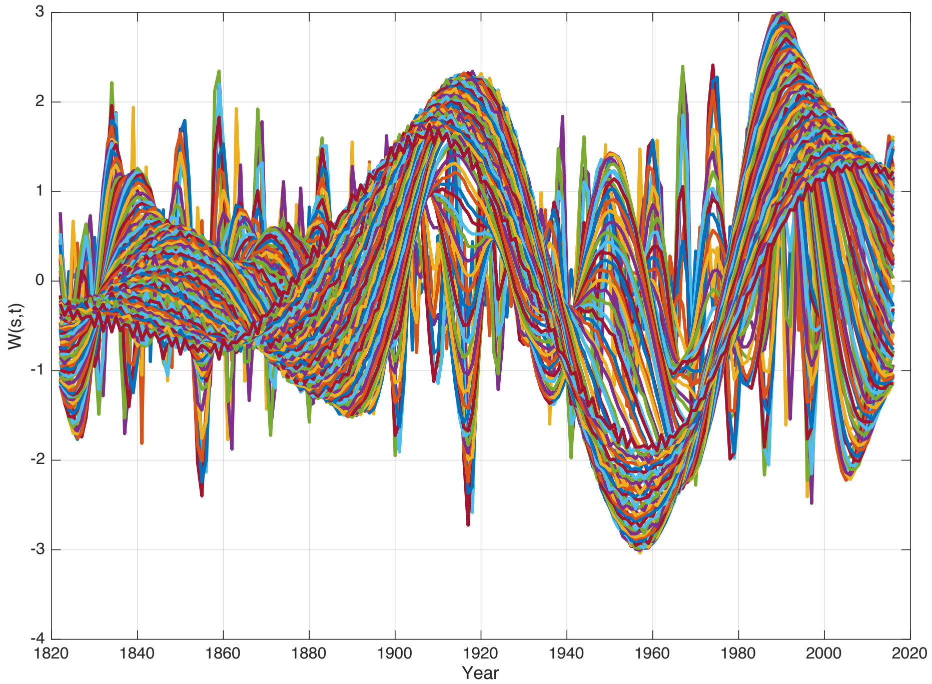

Figure 3. Wavelet spectrum W(nao, s, t) of the NAO winter index data series, for s = 1...0.6N and t=1900 to 2017.

Dominant period phase-relations

The computed wavelet spectrum W(nao, s, t) of the NAO-index series is shown on Figure 3. The wavelet spectrum W(nao, s, t) represents a time period from 1900 to 2013 and a wavelet scaling range is s = 1...0.6N, and the data series contains N = (2016-1822) = 194 data points.

Period amplitude-phase.
The wavelet spectrum W(nao, s, t) on Figure 3 shows:
P(nao, min, yr) = [(-1.5,1888),(-2.9,1957)]
P(nao, -0, yr) = [(0,1832), (0, 1899), (0, 1977)]
P(nao, max, yr) = [(0.49,1852), (2.19,1918),(2.9,1990)]
P(nao, +0, yr) = [1862, 1937, 2015]

The mean period
The period distance between min, -0, max, and +0 is w = [69,73,69,77], or a mean period a 72 years.

Upcoming next phase events
The upcoming next pase events are P(nao, min, yr,) = [1957+69=2026], P(nao, -0, yr) = [1977+73=2050]. P(nao, max, yr) = [1990+69=2059] and P(nao, +0, yr) = [2015+74=2089].

The identified dominant 72-year period and the period phase information may be confirmed by computing the wavelet power spectrum, the wavelet phase spectrum and the wavelet power spectrum.

2.1 THE WAVELET POWER SPECTRUM

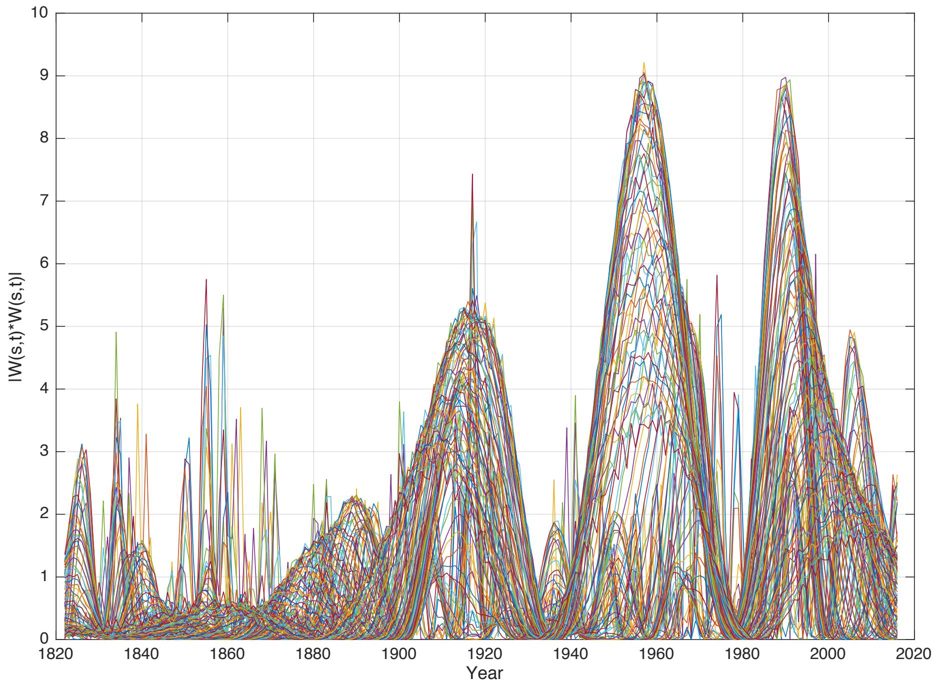

Figure 4. Wavelet power spectrum P(nao, s, t) of the NAO wavelet spectrum W(nao, s, t), for s=1...0.6N.

Period amplitude-phase

Figure 4 shows the power spectrum of the NAO winter index wavelet spectrum. The wavelet power spectrum is computed by WP(nao, s, t)=W(nao, s, t)*W(nao, s,t), and identifies the power of the most dominant periods in the wavelet spectrum. The power spectrum has a the amplitude phase information:

WP(nao, max, yr)= [(2.2,1888), (5.2,1917), (9.0, 1957), (8.9, 1991)].
WP(nao, 0, yr) = [(0,1900), (0,1935), (0,1980)]

Mean period

The mean distance between max and 0 states are: [40, 40, 34, 35,45], a mean distance of 38 years and a mean period of w = 76 years.

Upcoming next period state

If the dominant period of w = 76 years, we may separate the negative period in the power spectrum and compute upcoming next phase information
WP(nao, min, yr) = [1888, 1957, 1957+76=2033]
WP(nao, -0, yr) = [1900, 1980, 1980+76=2054]
WP(nao, max, yr) = [1917, 1991, 1991+76=2067]
WP(nao, +0, yr) = [1935, 1935+76=2020]

2.2 THE WAVELET PHASE SPECTRUM

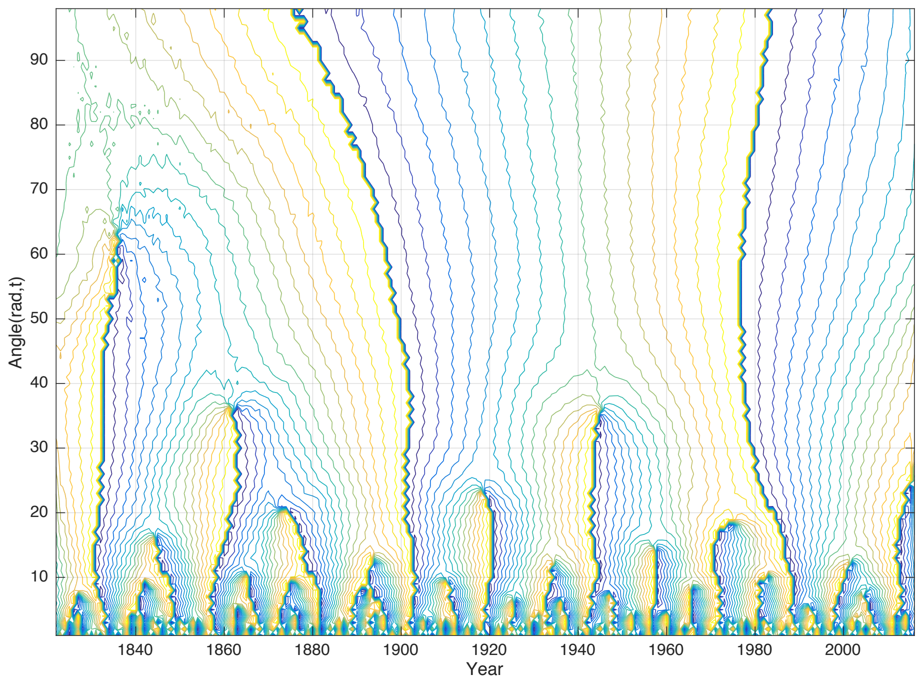

Figure 5. Wavelet phase spectrum WP(nao, s, t) of the NAO wavelet spectrum W(nao, s, t), for s=1...0.6N.

Period phase

A wavelet phase spectrum identifies long and short climate shifts periods. Figure 5 shows the wavelet phase spectrum from the NAO winter index. The wavelet phase spectrum WP(nao, s,t) is identified by computing a Hilbert transform of the wavelet spectrum and shown on Figure 4.

The wavelet phase spectrum WP(nao, s,t) has (-/+) phase shifts in the years:
WF(nao, -0, long) = [1833, 1902, 1978],
WF(nao, -0, short) = [1833, 1862, 1902, 1943, 1978],

Mean period
The long period has phase shift in a distance of w = [69, 76] years, or a mean period of 73 years. The short phase spectrum has a distance of: [29, 40, 41, 35] years, or a period of w = 39 years, which are close to 73/2 years.

The next -0 phase shift is estimated to the year. 1978 + 73=2051.

Upcoming next phase shifte
Identified and estimated upcoming next phase shifts are:
WF(nao, -0, 73) =[1833, 1902, 1978, 1978+73=2051]
WF(nao, -0, 39) =[1833, 1862, 1902, 1943, 1978, 1978+73=2017]

2.3 THE WAVELET AUTOCORRELATION SPECTRUM

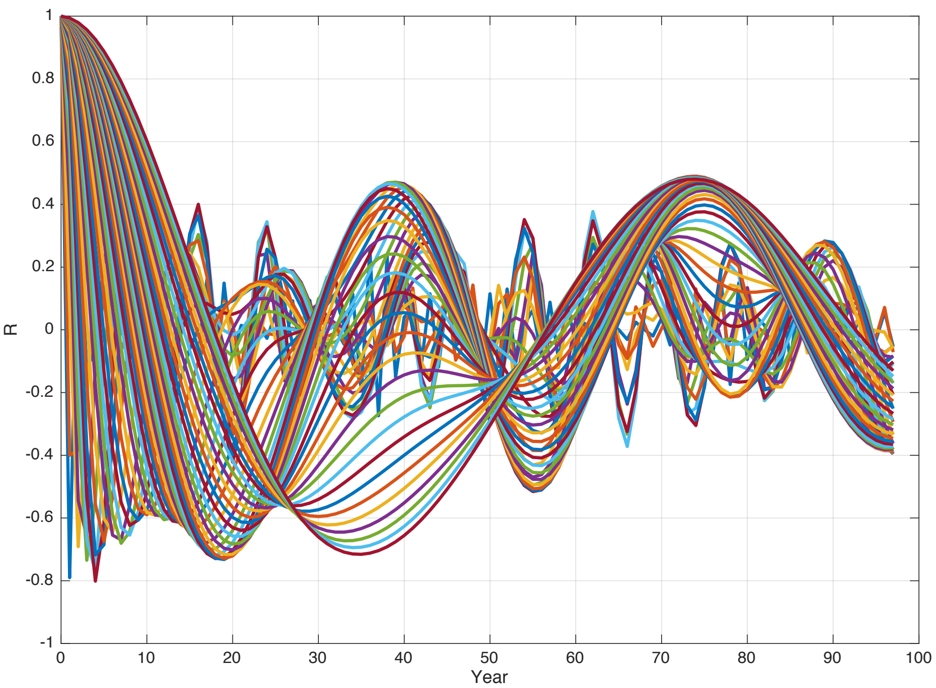

Figure 6. Autocorrelation spectrum RW(nao, s, m) of the Kola wavelet spectrum W(nao, s, t) for s=1 to 0.6N and m=0 to 58 .

Stationary periods in the wavelet spectrum W(nao, s, t) are identified by a correlation to periods in the autocorrelations of the wavelet spectrum. Figure 6 shows a set of computed autocorrelations WR(nao, s ,m) of the NAO Index wavelet spectrum W(nao, s, t). Dominant periods in W(nao, s, m) are:

WR(nao, r, m) =[(0.48, 8), (0.36, 39), (0.48,74), (0.36, 86), (0.35, 111), (0.23,151), (0.15, 181)].

Solar-lunar periods

The identified periods in WR(nao, r, m) has a possible relation to the solar – lunar periods:
Lunar periods: P(lun, w) = [18.6/2=9.3), (2*18.61=37.2), (4*18.6=74.4)]
Solar periods: P(sol, w) = [82.02, (10*11.1=111)]
Solar-Lunar periods: P(sol-lun, w) = [18.6/2=9.3), (2*18.61=37.2), (4*18.6=74.4), 82.02, (3*37.2= 111.6, 10*11.1=111), (3*61.2=183.6)]

Interference: 18.61-11.07 = 7.54 => 8 years

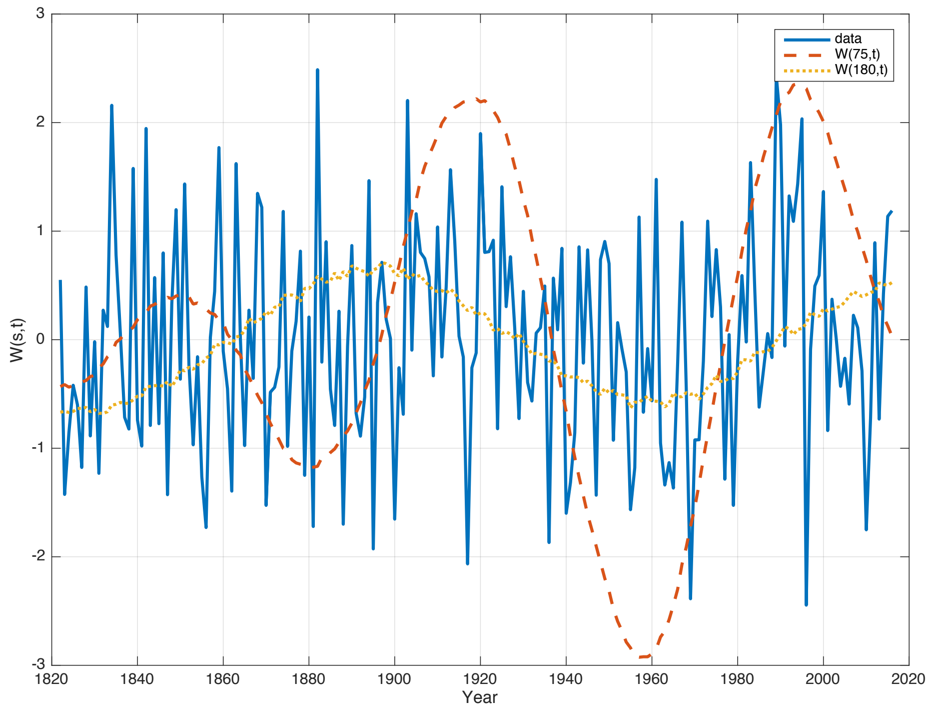

Figure 6 NAO winter index and dominant long periods

Figure 6 shows the NAO indenx (data), the stationary wavelet period W(nao, 75, t) and the stationary wavelet period W(nao, 180, t). The period phase information is:

W(nao, 75, -0, yr) = [(-0, 1835), (-0, 1977)]
W(nao, 75, max, yr) =[(0.5, 1849), (2.2, 1919), (2.4, 1994)]
W(nao, 75, +0) = [(+0, 1861), (+0, 1936), (+0, 2016)]

W(nao, 180, min) = [(-0.7, 1831), (-0.6, 1962)]
W(nao, 180 -0, yr) = [(-0, 1862), (-0, 1989)].
W(nao, 180, max, yr) = [(0.7, 1897), (0.5, 2016)].
W(nao, 180, +0, yr) = [(+0, 1928)].
W(nao, 180. min, yr) = [(-0.7, 1831), (-0.6, 1962)].

3 GENERAL NAO INDEX MODEL

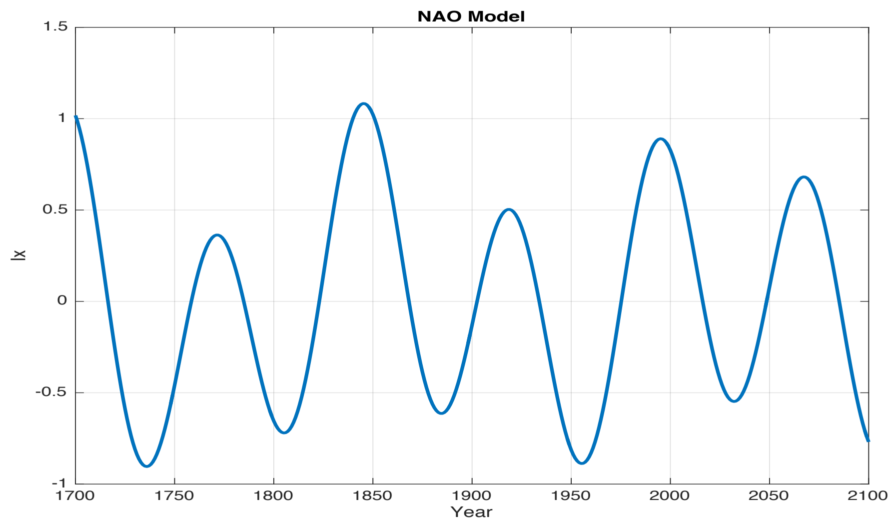

Figure 8. The NAO data series model P(nao, t) from the deterministic model (Mod).

The autocorrelations of the wavelet spectrum W(nao, s, t) shows that all dominant periods in the NAO data series variability, are related to the stationary 74.4 year Lunar nodal tide period and the 3(61.2) yr solar-lunar period. The identified stationary wavelet periods may be transformed into a set of deterministic periods by the simple model

P(nao, 74, t) = A(nao,74)cos(2pi(t-1994)/4*18.6)
P(nao, 180, t) = A(nai183)cos(2pi(t-1997)/3(61.2))
P(nao, t) = P(ko,74,t)+P(hsc,183,t)

where the period amplitude are: A(nao, 74)=2.4, A(nao, 183)=0.7. Selecting the same wavelet period in the wavelet spectrum identifies the period amplitude and phase.

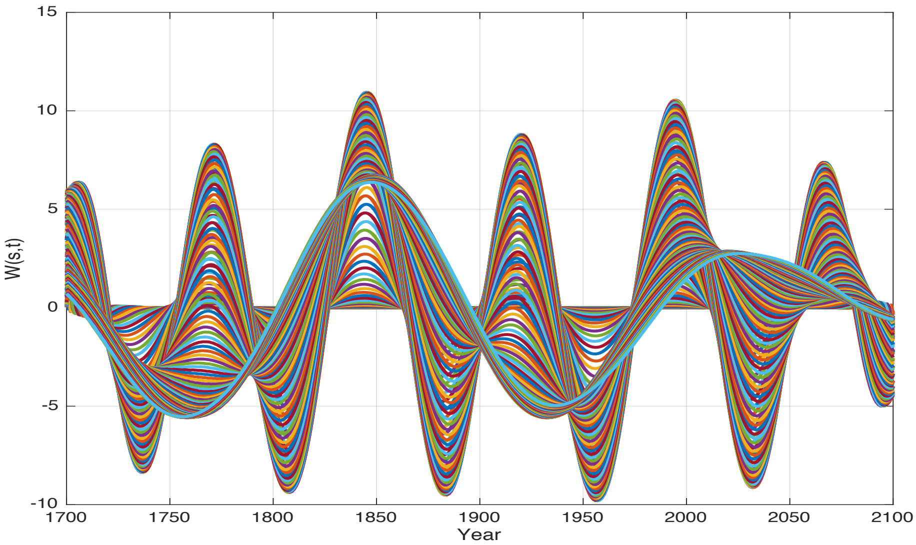

Figure 9. Wavelet spectrum W(nao-m, s, t) of the deterministic model of the NAO data series, for s=1...0.6N and t=1700 to 2100.

From this deterministic model, we can compute a future estimate of the NAO index variability. Figure 9 shows the wavelet spectrum from the deterministic model in the period 1700 to 2100. The wavelet spectrum shows that we may expect a new minimum in 2032 and a maximum at in 2067.

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