

North Atlantic Oscillation signals in the series of Beyşehir lake-levels (Turkey)

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Abstract. The North Atlantic Oscillation (NAO) is one of the major sources of interannual atmospheric variability over the Northern Hemisphere. In this study, we examined the variability of lake-levels of Lake Beyşehir in time-scale (period) domain using continuous wavelet transform (CWT) and global wavelet spectrum (GWS). The long winter (December, January, February and March) lake-level series and NAO index (NAOI) series were subjected to the wavelet transform. We constructed the NAOI series between 1960 and 2002 in relation to the lake-level recording period. The wavelet transforms of the NAOI time series presented as a three-dimension diagram showed different periodicities occurring in various time intervals. In short, we identified four main objects in this diagram during the above period. The center of the light tone regions in the diagram of CWT of Lake Beyşehir is located somewhere in the grid defined by a time band 1963-1979 and a scale band 5-year to 26-year. These long periodicities are coherent with the classical NAO winter peaks. In order to discover significant periodicities in Beyşehir lake-levels, we also calculated the GWS of the CWT. For the mid-term periodicities, the global spectrum magnitudes of Lake Beyşehir increased from 0.5-year to 10-year scale level. Although the periodicities more than 10-year scale level were detected, explaining significant relations between the NAO and these long-term periodicities remains a challenging task. The secondary cyclogenesis in eastern Mediterranean provides a physical linkage between the NAO (known as a key provider of precipitation to the Middle East region) and climatic surface variables in Turkey.

1. Introduction

Research on lake-levels has, in general, focused on the following themes: monthly changes in lake-level, annual variations, linkages with climate variability, and regulation and impacts issues. Water level fluctuations in lakes have been affected by hydrological, meteorological and anthropogenic conditions. The North Atlantic Oscillation (NAO) is one of the well known large-scale oscillations of atmospheric mass. It is presented by a meridional pattern occurring between the center of subtropical high surface pressure (located near the Azores) and the subpolar low surface pressure (located near Iceland)

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(Marchall et al., 2001). The NAO is one of the main modes of variability of the Northern Hemisphere atmosphere. During winter season, it exerts a strong control on the climate of the Northern Hemisphere. Polonskii et al. (2004) studied the characteristics of the NAO and pointed out that the spectra of NAO indexes have significant peaks at the periods 2-4 and 6-10 years.

Türkeş and Erlat (2003) showed that annual and, in particular, long winter precipitation for the period 1930-2000 tend to decrease during the positive NAO phase and increase during the negative NAO phase. Karabörk et al. (2005) recently documented the relationships between the NAO and various surface hydrologic and climatologic variables in Turkey. They determined a number of significant negative correlations with respect to the NAO index (NAOI). There are few studies concerning the lake-level variations using the wavelet transform. Among the exceptions, Hwang et al. (2005) demonstrated the wavelet spectra revealing annual and interannual variations of six lake-level series in China. All these lakes responded to the 1997-1998 El Niño episode and their wavelet spectra showed significant oscillations at different time-scale.

The goal of the current study is to explore how the NAO and lake-level fluctuations vary in the time-scale domain. Because the method of wavelet transform is an effective tool for examining nonstationary series, the relationships between the variability of the selected lake-levels across Turkey and the variability of the NAO were subjected to the both continuous and global wavelet spectrums.

2. Data and Methods

2.1. Data

The water level records of Lake Beyşehir used in this study were obtained through the General Directorate of Electrical Power Resources Survey and Development Administration (shortly abbreviated as EİE). The records consist of a period 1960-2002 with a total number of 170 continuous winter months. Figure 1 illustrates the time series the water level records of Lake Beyşehir. The lake is located in Mid-Anatolia Basin (western Turkey) with a surface area of 38,750 ha and a precipitation area of 3,095 km². The NAOI data was obtained through the Climate Analysis Section (NCAR). We focused only the last 43-year part of the NAOI data. Readers are referred to Karaca et al. (2000) and Ünal et al. (2003) for the general description of regional climatology.

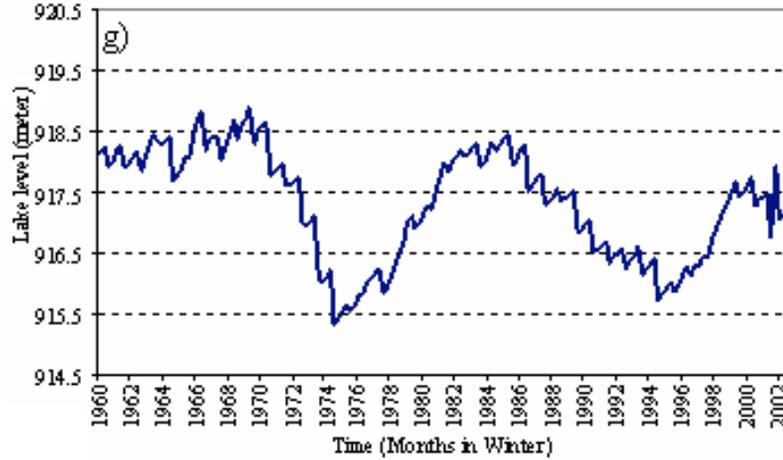


Figure 1. The records of long winter (DJFM) water level time series of Lake Beyşehir.

2.2. Wavelet analysis

For the climate analysis and predictions purpose, either wavelet spectrum or global spectrum has been widely used in recent years (i.e., Küçük and Ağralıoğlu, 2006). Wavelet decomposition is a way of analyzing a signal both in time and frequency domain. The wavelet spectrum based on continuous wavelet transform (CWT), is a natural extension of the conventional Fourier spectrum analysis and short time Fourier spectrum analysis which are commonly used in climatologic time series analysis (Drago and Boxall, 2002).

Assuming a continuous time series $x(t)$, the CWT is expressed by the convolution of $x(t)$ with a scaled and translated wavelet function $\psi(\eta)$,

$$W(\tau, s) = s^{-1/2} \int_{-\infty}^{+\infty} x(t) \psi^* \left(\frac{t - \tau}{s} \right) dt$$

where t stands for time; τ the time step in which the window function is iterated; $s \in [0, \infty]$ for the wavelet scale. (*) denotes complex conjugate. By changing both s and τ values gradually, it is possible to make a 2-D view of wavelet power, $|W(\tau, s)|^2$, indicating the frequency of peaks in the spectrum and how these peaks change with time. The wavelet analysis presents the time scale view of a signal. It is a process of decoding natural phenomena based upon their basic multi-fractal basis. The lower scales refer to a compressed wavelet, leading to capture abrupt changes (high frequency components of a signal). On the other hand, the higher scales, composed of the stretched version of a wavelet and the corresponding coefficients, represent slowly progressing occurrences or low-frequency components of the signal. For the global wavelet spectrum (GWS), let us consider a vertical slice through a wavelet plot as a measure of the local spectrum, the time-averaged wavelet spectrum over all certain periods or all the local wavelet spectra is then ex-

pressed as

$$\overline{W^2}(s) = \frac{1}{T} \sum_{t=0}^{T-1} |W_t(s)|^2$$

where T is the number of points in the time series. The time-averaged wavelet spectrum is called as global wavelet spectrum (GWS). The smoothed Fourier spectrum approaches to the GWS when the amount of necessary smoothing decreases with increasing scale. For this reason, the GWS offers an unbiased and consistent estimation of the true power spectrum that is functional tool for examining non-stationary climatic series. A global spectrum is calculated from the continuous spectrum; thus, timing of the periodic components can be also identified. Readers are referred to Torrence and Compo (1998) for further mathematical developments and explanations of the method of wavelet analysis.

The basis function in this analysis is obtained by the dilation and translation of the Morlet wavelet function (Panizzo et al., 2002):

$$\psi_0(t) = \pi^{-1/4} \left(e^{-iat} - e^{-a^2/2} \right) e^{-t^2/2}$$

We carried out the wavelet analysis by the “Rwave” module of the R software that is a system for statistical computation and graphics (<http://www.r-project.org>).

3. Results and Discussions

3.1. Analysis of long winter NAOI

In order to determine the effects of the NOA on the water levels of Lake Beyşehir, the records of long winter (DJFM) lake-levels were used in this investigation. It is important to know which and when periodic events had occurred in the long winter NAOI series. The wavelet transform of the NAOI time series is displayed in a 3-D fashion in Figure 2. In this diagram, we applied the CWT to the NAOI series that was chosen having a time period between 1960 and 2002 in relation to the lake-level recording period. In general, different periodicities have occurred in various time intervals. We identified four main objects in the Figure 2 during the period 1960-2002. In addition, we plotted a corresponding GWS of the long winter NAOI for the period 1960-2002 (Figure 3). The global spectrum was shown along with the 90% (the dashed line with triangles) confidence levels based upon the Markov process (red-noise process) by assuming a χ^2 distribution of the expected spectra divided by the red-noise spectra. Three main peaks were identifiable at 2.77, 5.31 and 8.28-year scale levels. It is worth noting that these are the major periodicities in the long winter NAOI series. Other noticeable features are 16- and 32-year events having a small magnitude in the global spectrum (Figure 3).

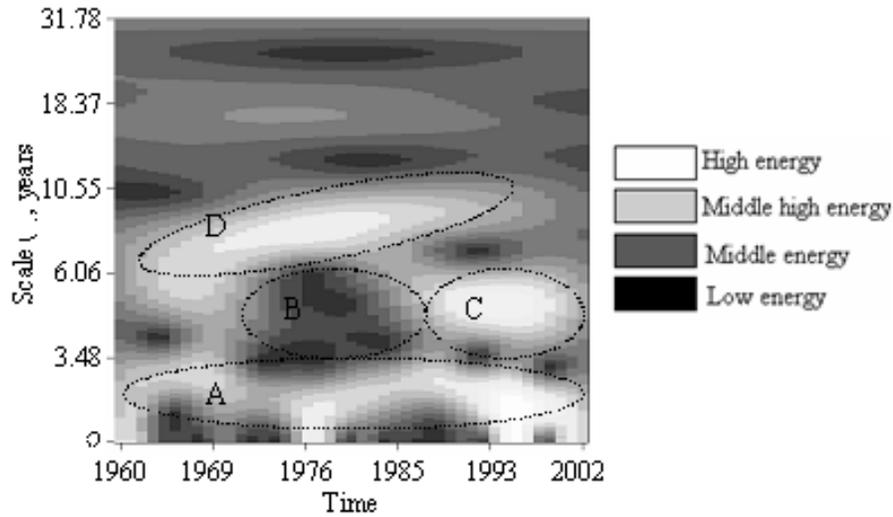


Figure 2. The wavelet transforms of the NAOI time series presented as a three-dimension diagram. Long winter averaged NAOI (4-month smoothed) series were obtained for the period 1960-2002.

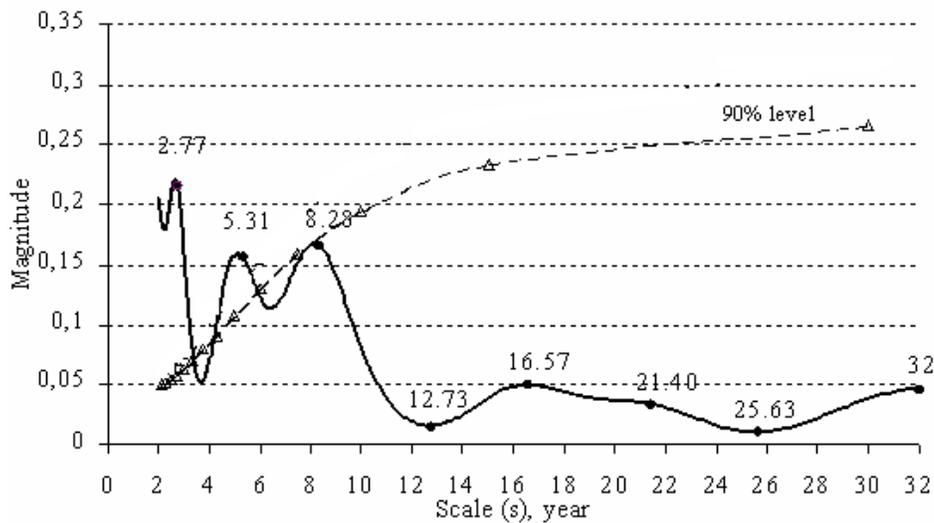


Figure 3. Global wavelet spectrum of long winter averaged NAOI (4-month smoothed) for the period 1960-2002. The 90% confidence levels of the Markov process is shown by the dashed line with triangles.

3.2. Analysis of Turkish lake-levels

The continuous spectrums of the Beyşehir lake-level series were calculated using unsmoothed winter months (DJFM) of each year (Figure 4). Each of 4-month seasons is assumed to represent one-year periodicity in the series. We did not take the outside regions of the dashed lines (the cone of influence)

into consideration. We extracted 170 winter seasons from the 43-year series to use in this continuous spectrum.

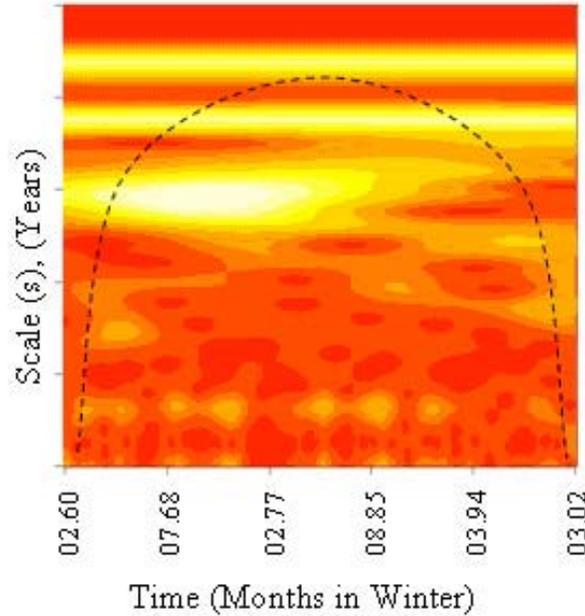


Figure 4. The continuous spectrums for the lake-level series were calculated using unsmoothed winter months (DJFM) of Lake Beyşehir. The dashed line delineates the cone of influence.

High (low) variance of wavelet coefficients is marked by light (dark) tones in Figure 5. The 43-year scale in this figure should be neglected because of the record length and the cone of influence. Due to large variations in the time series of Lake Beyşehir, there are three main objects in its diagram of continuous spectrums, where the highest coefficient magnitudes were determined (lightest tone region in the Figure 5f), and coincident with a period spanning from early 1960's to late 1980's. The centers of the light tone regions for Lake Beyşehir is located somewhere in the grid defined by a time band 1963-1979 and a scale band 5-year to 26-year. Moreover, the 32-year event, the longest periodicity, is scattered along the entire time scale as seen in Figure 4. One of the noticeable astronomic characteristics of the continuous spectrums is 12-month periodicity (annual cycle) detected at 1-year scale level in the vertical axis.

The 2–3 year and 6–10 year frequency bands of NAO series are common in the past 130 winters (Hurrell and Van Loon, 1997; Polonskii et al., 2004). The relationships between the normalized winter precipitation anomalies in Turkey and the winter NAOI anomalies are defined by significant negative correlations in the study of Türkeş and Erlat (2003), These are stronger in the middle and western regions of the country, a part of the central Anatolia region.

To discover significant periodicities in the lake-levels, we calculated the GWS of the continuous spectrum and showed in Figure 5 in which the smooth

line indicates a GWS of the winter NAOI and so does the smooth line with triangle for the lake-levels.

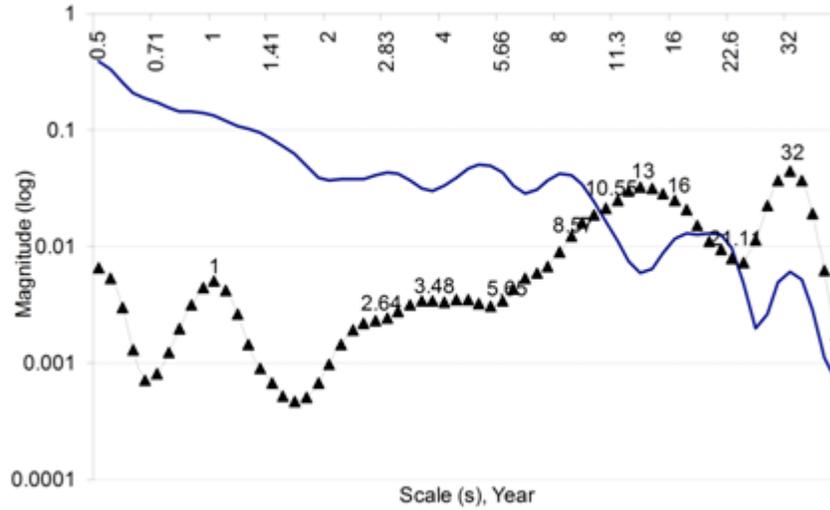


Figure 5. Global wavelet spectrums of continuous spectrums, shown in Figure 4, of the water levels of Lake Beyşehir. The smooth line indicates a global wavelet spectrum of the winter NAOI and the smooth line with triangle shows winter month lake-level global spectrum.

Besides the 16-year periodicity, the 32-year event is evident as well in the global spectrum diagram of winter NAOI series (Figure 5). The long-term periodicities (more than 10-year scale level) of winter NAOI global spectrum (smooth line) are generally compatible with those of the global spectrums of the lake levels. For the mid-term periodicities the results are not related; that is, the global spectrum magnitudes of Lake Beyşehir increase from 0.5-year to 10-year scale level as opposed to that of the NAOI.

4. Conclusions

The periodicities of Beyşehir lake-level series using the CWT were of our primary interest to describe the relations between the periodicities of the lake-levels and those of the NAOI. The time-scale analysis indicated that the main periodicities of NAOI series are less than 10-year events. However Lake Beyşehir, located in the Mediterranean transition region, showed notable periodicities in long-term (more than 10 years) scales. Considering the time-scale analysis, we believed that long-term events associated with different climatic effects due to the NAO are evident in the lake-level interannual fluctuations. According to Cullen and deMenocal (2000), the secondary cyclogenesis in eastern Mediterranean provides a physical linkage between the NAO (known as a key provider of precipitation to the Middle East region) and climatic surface variables in Turkey.

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