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Nonlinear Processes in Geophysics (2004) 11: 295–301
SRef-ID: 1607-7946/npg/2004-11-295

Nonlinear Processes in Geophysics

Atmospheric teleconnection patterns and eddy kinetic energy content: wavelet analysis

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Received: 27 January 2004 – Revised: 3 June 2004 – Accepted: 7 June 2004 – Published: 18 June 2004

Abstract. In this paper, we employ a non-decimated wavelet decomposition to analyse long-term variations of the teleconnection pattern monthly indices (the North Atlantic Oscillation and the Southern Oscillation) and the relationship of these variations with eddy kinetic energy contents (K_E) in the atmosphere of mid-latitudes and tropics. Major advantage of using this tool is to isolate short- and long-term components of fluctuations. Such analysis allows revealing basic periodic behaviours for the North Atlantic Oscillations (NAO) indices such as the 4–8-year and the natural change of dominant phase. The main results can be posed as follows. First, if the phases of North Atlantic and Southern Oscillations vary synchronously with the 4–8-year period then the relationship between the variations of the NAO indices and the K_E contents is the most appreciable. Second, if the NAO phase tends to abrupt changes then the impact of these variations on the eddy kinetic energy contents in both mid-latitudes and tropics is more significant than for the durational dominance of certain phase.

1 Introduction

Since last decades of past century, many scientists use the new powerful tool based on the wavelet decomposition for analyzing various signals. One can say without exaggeration, the wavelets has made revolution in both theory and practice of nonstationary signal processing. At present, the family of analysing function dubbed wavelets is being increasingly used in problems of pattern recognition; in processing and synthesising various signals, speech for instance; in analysis of images of any kind (these may be iris images, X-ray picture of a kidney, satellite images of clouds or a planet surface, an image of mineral, etc.); for study of turbulent fields, for contraction (compression) of large volumes of information, and in many other cases.

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Some ideas of the wavelet theory were partially developed a long time ago. For instance, A. Haar published as far back as a 1910 the complete orthonormal system of basis function with the local domain of definition, which are now named as Haar's wavelets. However one can note that probably first mention about wavelets has appeared in the literature on digital processing and analysing of geophysical signals (e.g. Goupillaud et al., 1982; Morlet et al., 1984). During the last years many scientists applied the wavelet transform for an analysis of meteorological time series. In particular, Astaf'eva (1996) concluded that the wavelet analysis of monthly mean values of the Southern Oscillation index reveals the self-similar structure of the data and the presence of a process resembling a cascade one on scales from a month to several decades (up to 70–80 years). Torrence and Webster (1999) analysed the system of the El Niño-Southern Oscillation and Indian monsoon. They showed that the wavelet power spectra and variance time series show interdecadal changes in 2–7 year variance, and indicate intervals of high variance (1875–1920 and 1960–1990) and an interval of low variance (1920–1960). Oh et al. (2003), by using wavelet decomposition based on non-decimated wavelet transform, detected the original periodicities, such as the Schwabe and Hale cycle of solar variability, in irradiance reconstructions. Also, they evaluated common temporal characteristics in both solar forcing and temperature series, focusing on the well known Gleissberg (around 85 years) and the sunspot cycle (around 11 years).

It is clear, although there are numerous investigations on the above mentioned methods, they can not embrace all meteorological applications. Therefore in current essay, using wavelet transform we attempt to explain the reasons of temporal fluctuations for eddy kinetic energy content (K_E), which can be considered as one of many parameters responsible for the intensity of atmospheric eddy evolution. The K_E content is determined by the perturbations of wind components from zonal mean state and the budget equation of this energy can be considered to examine the evolution of eddy activity. Here, we use wavelet decomposition to identify relationship between variations of the North Atlantic Oscillation (NAO) index and the K_E contents in the mid-latitudes and the tropics. The fact that the wavelet transform can reveal not only interaction of different processes but also its modification on various time scales is advantage of this method.

Let us consider briefly (complete review was given by Wanner et al., 2002) some characteristics of the NAO, which is one of the most prominent teleconnection patterns in all seasons and is documented by Barnston and Livezey (1987). The NAO consists of a north-south dipole of pressure anomalies with one centre located over Greenland and the other centre of opposite sign over the middle of the North Atlantic (between 35° N and 40° N). The phase of the NAO is defined by an index which measures (for example) the difference between the normalized pressures of Lisbon, Portugal and Stykkisholmur, Iceland (Hurrell, 1995).

The positive phase of the NAO corresponds to a strong westerly flow and reflects below-normal heights and pressure across the high latitudes of the North Atlantic and above-normal heights and pressure over the central North Atlantic, the eastern United States and Western Europe. The negative phase of the NAO corresponds to a weak westerly flow and reflects above-normal heights and pressure across the high latitudes of the North Atlantic and below-normal heights and pressure over the central North Atlantic, the eastern United States and Western Europe. Both phases of the NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of zonal and meridional heat and moisture transport (Hurrell, 1995), which in turn results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe. Also, the NAO affects many others processes such as the seasonal variations of atmospheric constituents (Appenzeller et al., 2000; Khokhlov and Glushkov, 2002b), the meridional heat transport (Häkkinen, 1999), the Arctic sea ice export (Hilmer and Jung, 2000), etc.

So, the aim of present paper is to analyse long-term variations of the North Atlantic Oscillation and the Southern Oscillation monthly indices and the relationship of these variations with eddy kinetic energy contents in the atmosphere of mid-latitudes and tropics.

2 Method and data

Wavelets are fundamental building block functions, analogous to the trigonometric sine and cosine functions. Fourier transform extracts details from the signal frequency, but all information about the location of a particular frequency within the signal is lost. In comparison, the multi-resolution analysis makes wavelets particularly appealing for this study, because they are localized in time and the signals are examined using widely varying levels of focus. For detail about wavelet theory, the monographs of Daubechies (1992) and Goswami and Chan (1999) can be recommended. Previously, continuous wavelet transform has been used to capture meteorological (Astaf'eva, 1996; Torrence and Webster, 1999) and solar signals (Fligge et al., 1999; Oh et al., 2003). In this article, we work with non-decimated (discrete) wavelet transform rather than continuous wavelet transform, because from a statistical point of view, they are well adapted (i.e. search for correlations or noise reduction) and offer a very flexible tool for analysis of discrete time series such as the ones under study here. The advantages of non-decimated wavelet transform also include (1) a much better temporal resolution at coarser scales than with ordinary discrete wavelet transform, and (2) it allows us to isolate time series of the major components of meteorological signals in a direct way. Here we provide a brief summary of the non-decimated wavelet transform; Oh et al. (2003) may be consulted for a more in-depth discussion.

The dilation and translation of one mother wavelet $\psi(t)$ generates the wavelet $\psi_{j,k}(t)=2^{j/2}\psi(2^j t-k)$, where $j, k \in \boldsymbol{Z}$. The dilation parameter j controls how large the wavelet is, and the translation parameter k controls how the wavelet is shifted along the t-axis. For a suitably chosen mother wavelet $\psi(t)$, the set $\{\psi_{j,k}\}_{j,k}$ provides an orthogonal basis, and the function f which is defined on the whole real line can be expanded as

$$f(t)=\sum_{k=-\infty}^{\infty} c_{0k}\varphi_{0,k}(t)+\sum_{j=1}^{J}\sum_{k=-\infty}^{\infty} d_{jk}\psi_{j,k}(t), \quad (1)$$

where the maximum scale J is determined by the number of data, the coefficients c_{0k} represent the lowest frequency smooth components, and the coefficients d_{jk} deliver information about the behaviour of the function f concentrating on effects of scale around 2^{-j} near time $k\times2^{-j}$. This wavelet expansion of a function is closely related to the discrete wavelet transform (DWT) of a signal observed at discrete points in time.

In practice, the length of the signal, say n, is finite and, for our study, the data are available monthly, i.e. the function $f(t)$ in Eq. (1) is now a vector $\boldsymbol{f}=(f(t_1), \ldots, f(t_n))$ with $t_i = i/n$ and i=1, …, n. With these notations, the DWT of a vector $\boldsymbol{f}$ is simply a matrix product $\boldsymbol{d}=\mathbf{W}\boldsymbol{f}$, where $\boldsymbol{d}$ is an $n\times1$ vector of discrete wavelet coefficients indexed by 2 integers, d_{jk}, and $\mathbf{W}$ is an orthogonal $n\times n$ matrix associated with the wavelet basis. The DWT is quickly computed through an efficient algorithm developed by Mallat (1989). For computational reasons, it is simpler to perform the wavelet transform on time series of dyadic (power of 2) length. In this paper this length is 512 months.

One particular problem with DWT is that, unlike the discrete Fourier transform, it is not translation invariant. This can lead to Gibbs-type phenomena and other artefacts in the reconstruction of a function. The non-decimated wavelet transform (NWT) of the data $(f(t_1), \ldots, f(t_n))$ at equally spaced points $t_i=i/n$ is defined as the set of all DWT's formed from the n possible shifts of the data by amounts i/n; i=1, …, n. Thus, unlike the DWT, there are 2^j coefficients on the jth resolution level, there are n equally spaced wavelet coefficients in the NWT:

$d_{jk}=n^{-1}\sum_{i=1}^{n}2^{j/2}\psi\left[2^j\left(i/n-k/n\right)\right]y_i,\ k=0,\ \ldots,\ n–1,$ on each resolution level j. This results in $\log_2(n)$ coefficients at each location. As an immediate consequence, the NWT becomes translation invariant. Due to its structure, the NWT implies a finer sampling rate at all levels and thus provides a better exploratory tool for analyzing changes in the scale (frequency) behaviour of the underlying signal in time. These advantages of the NWT over the DWT in time series analysis are demonstrated in Nason et al. (2000).

As in the Fourier domain, it is important to assess the power of a signal at a given resolution. In order to reach this goal, a time-domain model for encapsulating localized scale activity was proposed by Nason et al. (2000). An evolutionary wavelet spectrum (EWS) quantifies the contribution to process variance at the scale j and time k.

From the above paragraphs, it is easy to plot any time series into the wavelet domain. Another way of viewing the result of a NWT is to represent the temporal evolution of the data at a given scale. This type of representation is very useful to compare the temporal variation between different time series at a given scale. To obtain such results, the smooth signal S_0 and the detail signals D_j (j=1, ..., J) are defined as follows

$$S_0(t)=\sum_{k=-\infty}^{\infty}c_{0k}\varphi_{0,k}(t)\ \text{and}\ S_j(t)=\sum_{k=-\infty}^{\infty}d_{jk}\psi_{j,k}(t). \quad (2)$$

Sequentially, the temporal multi-resolution decomposition of a signal is derived from

$$D_j(t)=S_j(t)-S_{j-1}(t).$$

The fine scale features (high frequency oscillations) are captured mainly by the fine scale detail components D_J and D_{J-1}. The coarse scale components S_0, D_1, and D_2 correspond to lower frequency oscillations of the signal. Note that each band is equivalent to a band-pass filter.

Further we use the Daubechies wavelet (db15) as mother wavelet. This wavelet is biorthogonal and supports discrete wavelet transform (Daubechies, 1992).

Now, let us dwell on meteorological data about signals. As stated above, the eddy kinetic energy (K_E) is considered as the intensity measure of atmospheric eddy evolution. It can be calculated by

$$K_E=\frac{\overline{u'^2}+\overline{v'^2}}{2}, \quad (3)$$

where u and v are the zonal and meridional components of wind. The concept of zonal mean value and deviation from it is used in Eq. (3). Integration of K_E over the whole atmosphere at latitudinal belt gives a typical value of 10^5 and a dimensionality $J\ \mathrm{m}^{-2}$. Calculations are carried out for the latitudinal belts 0–30° N ($K_{E,tr}$) and 30–60° N ($K_{E,ml}$). The NCEP-NCAR 50-year reanalysis (Kistler et al., 2001) is used as the data for the calculations of K_E content.

In this paper we consider period from January 1948 to February 2003. As the number of months is not dyadic (662 months) the period is divided onto two sub-periods with length of the 512 months: first one starts since January 1948 and second one ends with February 2003. Then the non-decimated wavelet transform is applied for these sub-periods and derived detail components are glued together to obtain the maximum possible length.

3 Results and discussion

Let us make some notes before considering the results obtained in our study.

The NAO exhibits considerable short-term (approximately 10 days, e.g. DelSole, 2001; Benedict et al., 2004) and long-term (interseasonal and interannual) variability, and prolonged periods (several months if consider the monthly NAO index) of both positive and negative phases of the pattern are common. Additionally, the wintertime NAO exhibits significant interannual and interdecadal variability (Hurrell, 1995). For example, the negative phase of the NAO dominated the circulation from the mid-1950's through the 1978/1979 winter. During this approximately 24-year interval, there were four prominent periods of at least three years each in which the negative phase was dominant and the positive phase was notably absent. In fact, during the entire period the positive phase was observed in the seasonal mean only three times, and it never appeared in two consecutive years.

One important problem consists in the time resolution of the indices. NAO indices can be defined for series of winter average pressure (November to March, December to February), for monthly mean pressure, or for even shorter time periods such as 5 day or even one day means. Two station indices are perhaps sufficiently robust for defining seasonal means but can differ widely if used for shorter term sampling (Wanner et al., 2002).

Our early wavelet analysis, which was carried out with daily mean time series of the NAO indices and K_E content, showed that the relationship between these variables is not significant at the short-term time scale (up to the 1 year in our case). Nevertheless, this analysis allows to reveal some significant short-term variabilities including the above-mentioned 10-day cycle in the NAO index. Thus, by using daily mean data we should utilize very long time series to obtain long-term variabilities, whereas the fine scale detail components would not be informative. Furthermore, if compare the detail components obtained from very long daily mean time series of the NAO index with the ones obtained from monthly time series then the good agreement is observed between these components at the coarse scale (more than 2 years in our case). The analogous results were obtained for the time series of K_E content. The latter justifies the advantages of the non-decimated wavelet transform used in this paper.

A matrix of correlations of the winter (December to February) indices calculated by the different ways for the time period 1950 to 1994 has been presented in Wallace (2000). Not all correlations between these different indices are high. In our preliminary examinations we used three different indices:

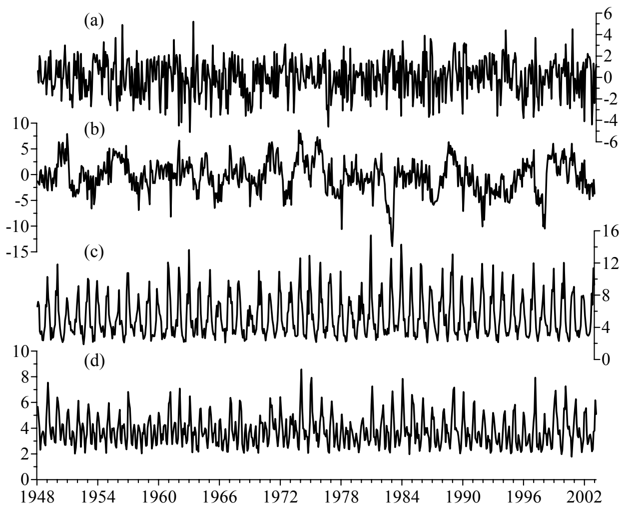

Fig. 1. Original time series of the North Atlantic Oscillation index **(a)**, the Southern Oscillation index **(b)**, the K_E contents (10^5 J m^{-2}) in the mid-latitudes **(c)**, and the K_E contents (10^5 J m^{-2}) in the tropics **(d)**.

the station-based NAO indices by Hurrell (1995), based on Stykkisholmur and Lisbon station data, the first principal component of the SLP field poleward of 20°N, and the index based on the temperature difference between Norway and Greenland (Wallace, 2000). To analyse the detail components for the monthly indices the method described in the previous section was utilised. It turned out that for the periods longer than approximately 2 years the correlation coefficients between the different indices are sharply increased and exceed the value 0.8 in most cases. Also, most of the maxima and minima were in close agreement. Hence, on conditions that we further analyse the long-term variations of the NAO indices, the assumption on the data independence for such variations can be accepted.

Thus, in present study we consider the long-term variations of the monthly NAO index calculated as the difference in the sea-level pressure between Lisbon (Portugal) and Stykkisholmur (Iceland). Motivation for such a choice is above grounded.

It was mentioned in the previous section, we use eddy kinetic energy as a measure of the wave activity in the atmosphere of the mid-latitudes and the tropics. On the other hand, the long-term variations of the K_E content can be considered as a manifestation of the climate dynamics. As earlier climate studies showed (Rind, 1986) for colder climate, the expected high-latitude amplification should lead to greater temperature gradients. In addition, the appearance of glaciers on land may well intensify the land-ocean temperature contrast. Colder climates thus should have increased available potential energy, which might then be expected to lead to increased baroclinic energy generation following the cycle toward the eddy kinetic energy. Also, these model results showed that the eddy kinetic energy definitely increases in colder climates, though it was pointed out that it is hard to establish a priori what will happen with the eddy kinetic energy as climate change.

On the other hand, the recent studies on the long-term variability of the NAO indices show following. First, Hurrell and van Loon (1997) found the considerable NAO index variations at quasi-biennial and quasi-decadal time scales for the last 130 years. At that, from the 1940s to the 1970s, a strong downward trend was observed, and a sharp reversal occurred in the last 25 years. It is necessary to keep in mind that analogous trends were observed for the global temperature in the above periods. Second, during the Late Maunder Minimum the negative indices of the NAO were observed (Luterbacher et al., 2001). Thus, if consider decadal and centennial time scales the conclusion on the dependence of the NAO index on the climate dynamics can be drawn. In other words, we consider two non-interdependent dynamical processes (long-term variations of the NAO index and K_E content), which are influenced the climate dynamics.

Figure 1 shows the original time series of the North Atlantic Oscillation index, the Southern Oscillation index, the K_E contents in the mid-latitudes, and the K_E contents in the tropics. It is naturally that the largest relationship is found for the K_E contents in the mid-latitudes and tropics. Even though for this case most of main maxima and minima are not coinciding. Also, by using these non-smoothed time series the conclusion on any long-term variabilities of time series is very hard drawn.

So, by using the multi-resolution decomposition, we characterize the major components of the variability for the monthly NAO indices and K_E content. Based on the inverse non-decimated wavelet transform, we can extract the signals S_0 and D_j, j=1, ..., 9 (in the time domain) from the wavelet coefficients c_0 and d_j (in wavelet domain).

At first, let us mention some information about long-term fluctuations in the atmosphere. Concerning eddy kinetic energy, the seasonal variations with 12-month period can be first noticed. The magnitude of K_E content is increased in the winter and has minimum in the summer (Khokhlov and Glushkov, 2002a). Also, the El Niño phenomenon with periodicity of 3–7 years needs to be kept in mind as its influence on the atmosphere is well known. Finally, there is the famous 11-year sunspot cycle. Although we still lack solid knowledge of how solar variations are translated through interaction with the atmosphere into a climate forcing, assuming that these external forcings influence climate in a consistent fashion, one would expect to find fingerprints of the perturbations both in terms of temporal evolution and magnitude (Haigh, 1999).

Naturally, the complex of contributions from each of above-mentioned (and not mentioned here) forcings determine the long-term variations of intensity of atmospheric processes. Thus, total-lot agreement of signals can not be revealed on all detail signals by analysing only some of them. Especially, since we analyse the derivative of these forcings here. Total coincidence for few signals is improbable even for certain chosen detail component. In other words, it is necessary to apply some quantitative criterion for a selection of

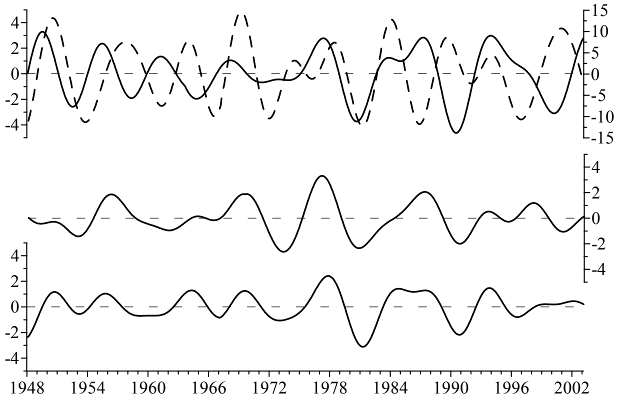

Fig. 2. The detail component D_4 for the North Atlantic Oscillation index (solid line of top panel), the Southern Oscillation index (dotted line of the top panel), the K_E contents in the mid-latitudes (middle panel), and the K_E contents in the tropics (bottom panel).

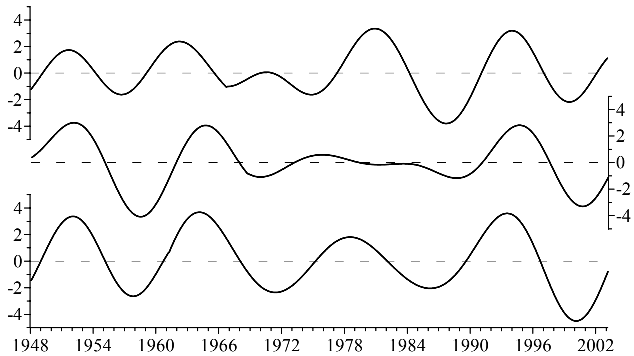

Fig. 3. The detail component D_3 for the North Atlantic Oscillation index (top panel), the K_E contents in the mid-latitudes (middle panel), and the K_E contents in the tropics (bottom panel).

most informative detail component. To this end, we consider the correlation coefficient for the signals of NAO indices and K_E content (see Table 1).

Table 1 shows that the detail component D_7 with the 1-year period has largest correlation coefficient $K_{E,ml}$–$K_{E,tr}$. These fluctuations relate to the seasonal variations taking place in the atmosphere during the change from the winter to the summer. Such a high correlation is observed for most of meteorological series with the 1-year period. The greatest correlation coefficients between the NAO indices and the K_E contents are registered for the low-frequency spectrum (D_1–D_4). In addition, in case of the D_3 and D_4 the essential relationship between $K_{E,tr}$ and $K_{E,ml}$ take place but for the rest this relation is opposite and is not so essential. The latter causes the conditions, which are characterized opposite sign of the correlation coefficients NAO-$K_{E,ml}$ and NAO-$K_{E,tr}$ for the detail components D_2 and D_1. Thus, in further examination we will work with the detail components D_4 and D_3. A consideration of signals with periods larger than 20 years (as for instance periods of D_2 and D_1) not make sense in our case since the duration of whole period under review is a little larger than the 42 years.

Figure 2 shows the detail component D_4, which is interesting by its period of oscillation (4–8 year) and namely on these durations the maximal anomaly of pressure in the NAO falls (da Costa and de Verdiere, 2002), though one can be noted they used another mathematical tool. Also, Fig. 2 confirms the particular advantage of wavelet decomposition namely its flexibility in the adjustment to the local changes of the NAO period, which are wide-ranging. Since wavelets support clear minima and maxima they take into account realistic estimations of cycle-length.

From July 1960 to January 1990 there exists the larger agreement between the NAO indices and the K_E contents. Such a case is presented in Fig. 2. The correlation coefficients for this period amount to 0.76 and 0.70 for the NAO-$K_{E,ml}$ and the NAO-$K_{E,tr}$, respectively, while for period of January 1990–February 2003 they are −0.05 and 0.58, respectively. At the same time during the sharper change of NAO indices there exists the same essential variation of eddy kinetic energy content. Generally, the synchronous changes of the NAO phase and K_E content in the tropics with the period larger than 4 year look surprising. However one can recall that the El Niño periodicity, as stated below, amounts to from 3 to 7 year and the correlation coefficient for the North Atlantic and Southern Oscillations during the period of mid-1960's – mid-1980's is 0.60 but since 1985 is −0.51 (see Fig. 2a). This implies that the relationship between the changes of the NAO indices and the K_E contents both in the tropics and in the mid-latitudes varies depending on the phase or antiphase is registered for the North Atlantic and Southern Oscillations. For the first case this relationship is stronger.

Now we analyse the detail component D_3 (Fig. 3). First note that this signal characterises a dominance of negative or positive phase of the NAO during long period of time. It is well known (Hurrell, 1995) that the negative phase of the NAO dominated the atmospheric circulation from the mid-1950's to the 1978/1979 winter. An abrupt transition to recurring positive phases of the NAO then occurred during the 1979/1980 winter, with the atmosphere remaining locked into this mode through the 1994/1995 winter season. During this 15-year interval, a substantial negative phase of the pattern appeared only twice, in the winters of 1984/1985 and 1985/1986. However, November 1995–February 1996 was characterised by a return to the strong negative phase of the NAO. Figure 3 (top panel) displays all these variations.

Secondly during the durational negative NAO phase till January 1980 the correlation coefficients NAO-$K_{E,ml}$ and NAO-$K_{E,tr}$ amount to 0.09 and 0.37 respectively. On the other hand, second half of considered period is characterised by the correlation coefficients 0.76 and 0.68. In other words, if the NAO phase tends to the sharp changes then its influence is stronger on the eddy kinetic energy content both in the tropics and in the mid-latitudes. This can be explained by the basic reconfiguration covering most of the mid-latitudes and

Table 1. Correlation coefficients between the components of detailed signal for the NAO indices and the mid-latitude K_E content (NAO – $K_{E,ml}$), the NAO indices and the tropical K_E content (NAO – $K_{E,tr}$), and the mid-latitude K_E content and the tropical K_E content ($K_{E,ml}$–$K_{E,tr}$).

	Correlation coefficients for components								
	D_9	D_8	D_7	D_6	D_5	D_4	D_3	D_2	D_1
NAO – $K_{E,ml}$	0.123	0.134	0.221	0.163	0.321	0.579	0.693	0.824	0.854
NAO – $K_{E,tr}$)	0.156	0.112	0.387	0.210	0.398	0.643	0.668	−0.805	−0.778
$K_{E,ml}$–$K_{E,tr}$)	0.271	0.593	0.911	0.458	0.341	0.737	0.844	−0.381	−0.305

tropics when the North Atlantic Oscillation phase is changed. In this case, there exists the significant meridionality of air currents and this implies the K_E contents increasing. Let us remark that the period of detail component D_3 amounts from 9 to 13 years, i.e. the 11-year solar cycle approximately. Nevertheless the interdependency between these two signals is not revealed.

4 Conclusions

The advantage of using our decomposition of teleconnection pattern indices and eddy kinetic energy content is to isolate short- and long-term components while retaining the flexibility for variability in the cycle length.

By using wavelet decomposition based on the non-decimated wavelet transform we reveal some basic periodicities for the North Atlantic Oscillation indices such as the 4-8-year cycle, which is characterised by the maximum of atmospheric pressure anomaly, and the natural change of dominant phase. These fluctuations are analysed together with the eddy kinetic energy contents in the mid-latitudes and tropics.

Main results of analysis carried out in present paper can be briefly stated as follows:

i) if the phases of the North Atlantic and Southern Oscillations vary synchronously with the 4-8-year period then the relationship between the variations of the NAO indices and the K_E contents is the most appreciable. In the converse case, if above oscillations is at antiphase then the correlation coefficient NAO-$K_{E,ml}$ is unessential and the correlation coefficient NAO-$K_{E,tr}$ varies incidentally. Thus we may assume that there exists the influence not only of the North Atlantic Oscillation but also of the Southern Oscillation on the eddy kinetic energy content;

ii) if the NAO phase tends to abrupt changes then the impact of these variations on the eddy kinetic energy contents in both mid-latitudes and tropics is more significant than for the durational dominance of certain phase.

From our point of view, since the relationship between the considered atmospheric teleconnection patterns and the K_E contents is observed at the long time scales, this fact can be explained as the influence of climate change on the processes large-scale atmospheric dynamics, rather than the interaction effects between these processes.

Hence we can consider that method used here allows to identify prominent physical behaviours of large-scale atmospheric dynamics and to reveal the detailed characteristics of dominant teleconnection patterns.

Acknowledgements. The authors are indebted to anonymous reviewers for critical reading and valuable comments. These were very helpful for deeply considering the physical meanings of derivations and for improving the presentation of the manuscript.

Edited by: R. Grimshaw
Reviewed by: 2 referees

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