Inter-Decadal Variability of the Wind Mode in the Black Sea Region

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The surface pressure over the Black Sea in January–March, 1948–2012 is considered in the present article. The obtained climatic atmospheric pressure trends in this area reflect the relevant trends in the atmospheric circulation variability. It is shown that since the second half of the twentieth century, the North Atlantic Oscillation index (NAO), which characterizes the atmosphere circulation over Europe, showed the trend to the growth, where since the 1950's in the winter season was dominated by the zonal transfer in the atmosphere over Europe. At that the Black Sea region was mainly in the anticyclonic circulation area. It was found that the negative phase of the NAO surface the pressure oscillations over the western part of the sea were more than the average multi-annual one, than over its eastern part, and in the positive phase of the NAO – less.
Analysis of the spatial variability of anomalies of surface wind speed module in the Black Sea region showed during the even cycle, i. e. when the positive phase of the North Atlantic oscillation (NAO) index is mainly predominant, negative anomaly of the wind speed module is formed over the western part of the sea, whereas positive one –over the eastern part. The marked negative trend in wind speed module on coastal hydrometeorological stations confirms the trend to an increase in the influence of the Azores and Siberian anticyclone in the pressure field of the Black Sea region. Taking into account the positive phase of NAO is advantageously implemented during the even solar cycle and the negative one – during the odd cycle. It was found that in the even years of the cycle the maximum surface wind speed is observed over the eastern part of the Black Sea, the lowest one – over the western part. During the odd cycle of solar activity the signs of the surface wind anomaly modules above the western and eastern parts of the sea are changed into opposite ones.

Keywords: atmospheric circulation, solar activity, wind speed module, pressure anomalies, Black Sea, North Atlantic oscillation.

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Introduction. Since the second half of XX century a negative trend of the wind speed in the Black Sea coastal regions was observed [1]. At the same time during last 30 years the westerly and south-westerly speeds grew [2]. Based on the observations on the Crimea South coast (CSC), change of direction of strong winds (25 – 30 m/sec) was, to some extent, of a cyclic recurrence character [3] related to variability of the atmospheric circulation in the Atlantic-European sector which was conditioned by the North Atlantic oscillation (NAO) index. It is known that temperature fields in the western and eastern parts of the Black Sea ambiguously respond to the NAO variability [4]. Some estimates show that the same ambiguous behavior is characteristic of the wind speed field and, therefore, of the wind waves' field. It is shown in [2], in particular, that the wave maximum heights in the coastal zone of the Crimea south-western part were observed during the period when the NAO index values were mainly negative (NAO ≤ -1). On the other hand, the researches on CSC [3, 5] provide a ground to assume that the wave maximum heights in this region were observed mainly in the period when the NAO index values were positive (NAO – ≥ 1). Such a difference in manifesting extreme waves in two indicated regions at positive and negative NAO phases can be explained by a feature in the baric field structure over the western and eastern parts of the Black Sea. This feature is formed by the atmospheric circulation represented by the NAO index which, in its turn, is noticeably different during even and odd cycles of solar activity [4].

The aim of the paper is to study spatial structure of winter anomalies of the surface wind speed module over the Black Sea area during even and odd cycles of solar activity.

The applied data and method of research. The features of the surface pressure structure over the Black Sea area can be determined having conditionally divided the basin into the western and eastern parts along the meridian 34 °E. For this purpose, three points (on the latitude 42 °N) in the western part of the sea and two ones in its eastern part were chosen from the *NCEP/NCAR* array [6]. Average anomalies of the surface pressure were calculated, then the surface pressure gradient (anomalies difference), between the western and eastern parts of the sea was calculated. All the calculations were done for a winter season (January, February and March).

The module of the surface wind speed in the Black Sea region was chosen from the *NCEP/NCAR* array [6]. Then its average values for January – March, 1948 – 2012, (U_{av}, m/sec), were calculated for each point of the region. The deviations (anomalies) of the wind speed module for January – March of each year ($U'_I = U_i - U_{av}$, where i denotes a year) were found relative to these average values. To calculate spatial structure of the anomalies of the wind speed module, the data on the whole Black Sea region bounded by the co-ordinates 40 – 50°N and 25 – 42°E were used.

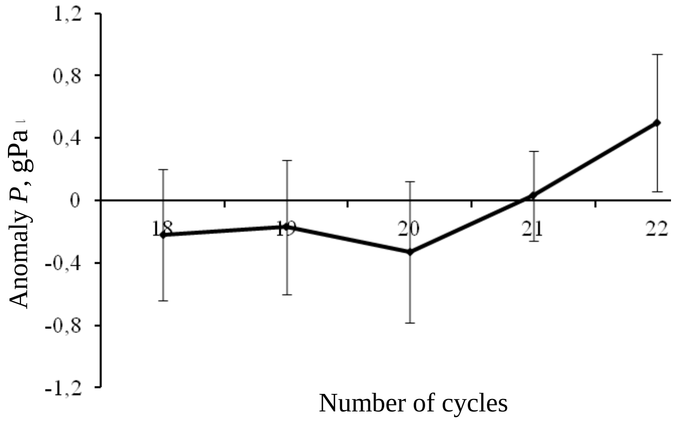
The trend characteristics of the wind speed module were assessed based on the coastal hydrometeorological stations' data from the archive of the Marine hydrophysical institute, RAS MHI. The surface pressure trends were estimated based on the *NCEP/NCAR* array data.

The obtained results and their analysis. The surface pressure over the Black Sea is formed by the atmospheric circulation in the Atlantic-European sector. Climatic trends of the atmospheric pressure in this region reflect the corresponding tendencies in variability of the atmospheric circulation. It is shown in [7, 8] that since the second half of XX century the NAO index characterizing the atmosphere circulation over Europe, showed a tendency to growth. Thus, since the 50-ies the zonal transfer in the atmosphere over Europe prevailed in winter, at that the Black Sea region was mainly in the area of anticyclonic circulation. It was also supported by impact of the Siberian anticyclone on this region in a winter season. The negative trend of the wind speed module obtained from the coastal hydrometeorological stations' data and noted in [1] confirms a tendency to increase of impact of the Azores and Siberian anticyclones on the baric field of the Black Sea region. It is evident from comparison of the inter-decadal changes of surface pressure over the Black Sea and in the southern spur of the Siberian anticyclone. For better obviousness, we will represent initial data as yearly averaged 11-year cycles of solar activity. The time series under study constituted an interval from 1948 to 1996. The time intervals correspond to the following numbers of the 11-year cycles:

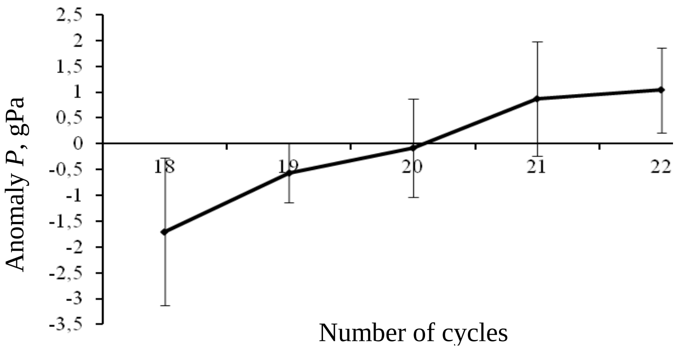
Cycle number	18	19	20	21	22
Years	1945 – 1954	1955 – 1964	1965 – 1976	1977 – 1986	1987 – 1996

Let us use the "Chersonesos lighthouse" data as an example of a decadal variability of the wind speed module, and the surface pressure over the western Black

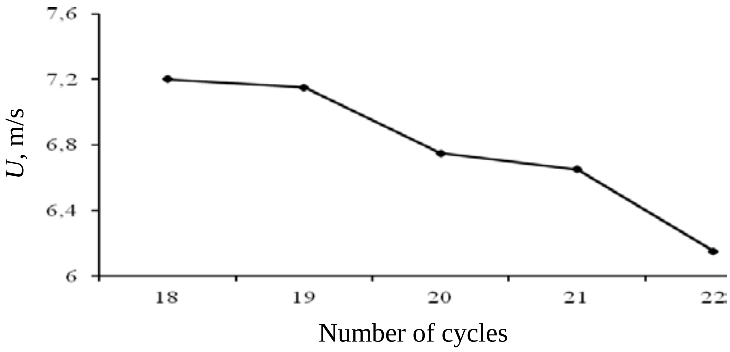
Sea and the Lake Balkhash region will be taken from the *NCEP/NCAR* array [6]. Note that variability of the surface pressure anomalies over the western Black Sea completely corresponds to similar variability over the whole sea area. Fig. 1, *a*, *b* shows the character of these parameters' variability for the time period under investigation, Fig. 1, *c* shows that of the wind speed module.



a



b



c

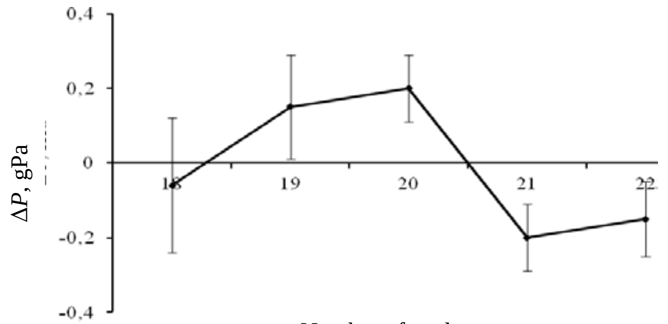
Fig. 1. Inter-decadal variability of surface pressure anomalies averaged for January – March in the western Black Sea (*a*), in the Siberian anticyclone southern spur (*b*), and that of the surface wind speed module based on the data of the hydrometeorological station "Chersonesos lighthouse" (*c*)

In the second half of XX century the surface pressure over the Black Sea and in the Siberian anticyclone southern spur demonstrates obvious tendency to growth. In the Black Sea region this process became especially apparent starting from the second half of the 70-ies, i.e. during the so-called climatic shift [9]. Since then the area of the increased atmospheric pressure characterized by predominance of anticyclonic conditions in the atmosphere circulation was, presumably, intensively formed in the Black Sea region. It is reasonable that in course of the years under study, such a tendency in variability of the baric field over the Black Sea resulted in a negative trend of the surface wind speed.

Alongside with the noted background tendency in the surface pressure field the Black Sea region, there are more “fine” features in the character of its redistribution between the western and eastern parts of the sea. It is shown in [4] that these features represented as differences between the pressure anomalies in the western and eastern parts of the sea permit to assess change of sign of ΔP depending on the atmospheric circulation in the Atlantic-European sector. Fig. 2, *a* shows interdecadal variability of the pressure gradient ΔP depending on the NAO index.

It follows from Fig. 2, *b* that the NAO minimum values were observed in the 19^{th} cycle, i. e. during maximal solar activity of the secular cycle [7, 8]. Later on and by the end of XX century the NAO index increased continuously. It testifies to the fact that during the time interval under study, the pressure trend in the Azores maximum was positive. Comparison with Fig. 1, *b* permits to assume that in the second half of XX century variability the Azores and Siberian maximums was characterized by a positive trend. According to [10] at high positive NAO index values, the cyclones’ trajectories are displaced to the north of Europe thus forming mainly anticyclonic conditions of circulation over the southern part of the continent. But the most significant change of the atmospheric circulation over the Black Sea took place when the NAO index achieved 0.5 during the climatic shift (the 21^{st} cycle of solar activity). According to the estimates in [7] the NAO index = ± 0.5 characterizes climatic conditions of the atmospheric circulation. The NAO index = = 0.44 observed at the beginning of XXI century provides a ground to assume that within a few next years the Black Sea region will be influenced by the atmospheric circulation conditions close to normal. How can it result in the field of the surface pressure gradient over the sea area? It follows from Fig. 2, *a* that during the period when the NAO index values are mainly low, the surface pressure over the western part of the sea is higher than that over the eastern one. During the period when the index values are high the situation is opposite. The surface pressure amplitudes are small, but such a redistribution of the surface baric field between the western and eastern parts of the sea can influence formation (transformation) of baric systems in the lower troposphere that, undoubtedly, should affect the features of the surface wind fields’ formation.

It is necessary to take into account that, as a rule, during an even cycle of solar activity the NAO index takes on the higher values than during an odd cycle. According to our estimates, the NAO index equals 0.5 (±0.5) when the values are averaged for 6 even cycles of solar activity and it equals 0.04 (±0.41) when the values are averaged for 7 odd cycles. The NAO index values are accompanied by the confidence intervals (in brackets) corresponding to the confiding probability 95 %. Note that, according to the hypothesis on equality of two distribution centers [11], the difference between the NAO indexes in the even and odd cycles of solar activity is also significant and achieves 95 %.



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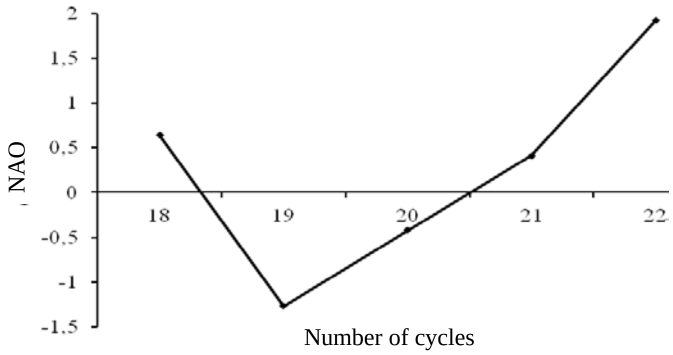

b

Fig. 2. Inter-decadal variability of difference of surface pressure anomalies in the western and eastern parts of the Black Sea (*a*), and that of the NAO index (*b*)

Having taken into account this result, let us analyze spatial distribution of the anomalies of the surface wind speed module in the Black Sea region which is shown on Fig. 3. For better evidence, the anomalies are represented on the area exceeding that of the Black Sea. It is seen that during an even cycle of solar activity when the NAO index takes on maximum values and the surface pressure over the western part of the sea is lower than that over the eastern one, the surface wind speed over the eastern part becomes maximal, whereas over the western part – minimal (Fig. 3, *a)*. During an odd cycle of solar activity when the surface pressure over the eastern part of the sea is lower than that over the western part, the surface wind speed over the eastern part becomes smaller than over the western one (Fig. 3,*b*). These features of spatial distribution of the anomalies of the surface wind speed module permit to expect that during an even cycle of solar activity the wind conditions exceeding the normal ones, most, probably, will take place over the eastern part of the sea in winter. Thus, the wind speed over the eastern Black Sea, most likely, will be higher than that over the western part.

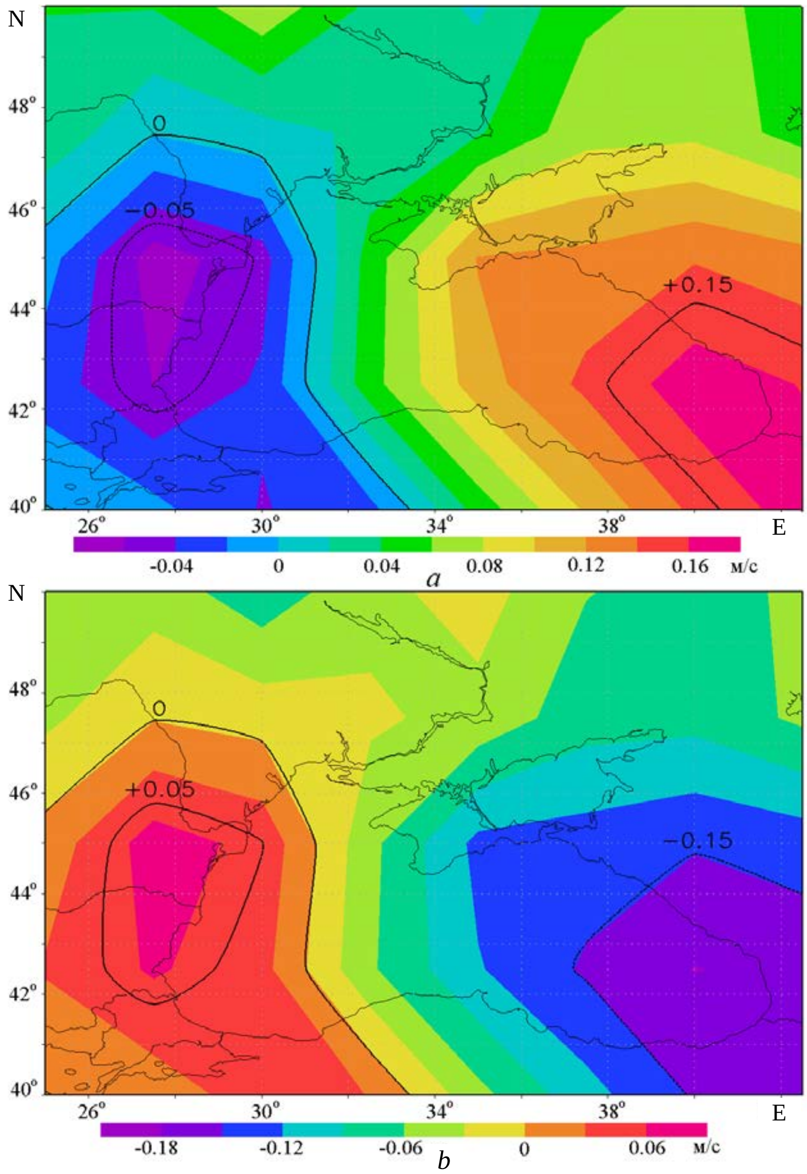

Fig. 3. Spatial distribution of the anomalies of the surface wind speed module during even (*a*) and odd (*b*) cycles of solar activity

Conclusion. Solution of the problem on ambiguousness of response of the surface wind field to disturbance of the baric field in the Black Sea region during even and odd cycles of solar activity permitted to obtain the following results.

In the second half of XX century the surface baric field over the Black Sea area exhibited a tendency to growth. The growth became especially noticeable since 1977 (the 21st cycle of solar activity) when, according to some estimates, a shift in the climatic system began to show. The surface pressure increase formed the conditions characteristic of the atmosphere anticyclonic circulation over the

Black Sea that resulted in weakening of the surface wind (data of the coastal stations).

Since the 19th cycle (1955 – 1964), the atmosphere circulation in the Atlantic-European sector conditioned by the NAO index tended to zonal transfer which was most obviously manifested during the climatic shift (the 21st and the 22nd cycles of solar activity). At that difference of the surface pressure anomalies over the western and eastern parts of the Black Sea was maximal during the NAO index negative phase and minimal – during its positive phase. It means that when the NAO index is minimal the surface pressure over the western part of the sea is higher than that over the eastern part. And vice versa, when the NAO index is maximal the surface pressure over the eastern part of the sea is higher than that over the western part. Such an uneven distribution of pressure anomalies results in the alternating-sign distribution of the anomalies of the surface wind speed module over the Black Sea region. Having taken into account the fact that the NAO index positive phase takes place, mainly, during an even cycle of solar activity, and its negative phase – during an odd cycle, we have obtained the assessments of spatial distribution of the anomalies of the surface wind speed module over the sea region. It is revealed that during an even cycle the surface wind maximum speeds are observed over the eastern part of the sea, and minimum ones – over the western part. During an odd cycle the anomalies' sign of the surface wind speed module over the eastern and western parts of the Black Sea changes.

At present the Black Sea climatic system is within the even cycle of solar activity (the 24th cycle). Therefore, one can expect that, most probably, winters in the current time interval will be characterized by the heightened wind speeds over the eastern part of the sea and by the lowered ones – over the western part.

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