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COMPARATIVE ANALYSIS OF MULTIDECADAL VARIABILITY OF HYDROMETEOROLOGICAL PARAMETERS IN THE PONTO-CASPIAN SEAS

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NCEP/NCAR reanalysis data for the period of 1948–2020 were used to detect, describe (in geographical sense) and compare the patterns of multidecadal variability of the hydrometeorological parameters (thermal, dynamic and humidity) in the Ponto-Caspian region (Black Sea, Sea of Azov and Caspian Sea). Polynomial approximations of the time series of the annual mean values indicated the non-linear nature and periodicity of the long-term variability of considered parameters. Being geographically closely located, these seas reveal significantly different patterns of variability. In the Black Sea two temporal intervals of an average duration of 20 and 40 years with multidirectional trends of hydrometeorological parameters changes have been detected, while in the Caspian Sea three such intervals lasting 10–25 years are identified. The North-Eastern wind regime prevails over the both basins. However, if in the Black Sea wind components act unidirectionally (air temperature rise/cooling coincides with the weakening/strengthening of both components), then in Caspian they act the opposite way, with the major portion of heat advection provided by zonal (Eastern) transport. Phases of air warming/cooling in both basins coincide with a weakening/strengthening of this transport. The time lag between the shift of dynamic and thermal (as well as humidity) regimes is about 6–8 years, suggesting a leading role of the large-scale atmospheric forcing variations in the regional variability. Specific humidity is positively correlated with air temperature and decreases/increases during periods of cooling/warming. In contrast, relative humidity and precipitation rate variations are negatively correlated with air temperature trends. Over the Caspian Sea intensification of Eastern transport and associated cooling coincide with a situation when the North Atlantic Oscillation (NAO) index decreases to negative values, and the East Atlantic-West Russian pattern (EAWR) index is significantly positive. On the contrary, weakening of the Eastern transport and warming occur during a period of sharp strengthening of the NAO, coinciding with strongly negative values of the EAWR index. As for the Black Sea, the situation is controversial: the general pattern of variability in 1948–1992 was similar to that in the Caspian Sea and consistent with described combinations of indexes. However, after 1992 no pronounced trend in variability of North-Eastern transport have been observed.

Keywords: multidecadal variability, air temperature, sea surface temperature, wind regime, atmospheric humidity, Ponto-Caspian seas

1. Introduction

The water bodes of the Ponto-Caspian basin (Black Sea, Sea of Azov and Caspian Sea) have common geological history, similar salinity conditions (brackish) and located in the same climate zone. They merged in the past into a single pool several times, most recently in the Pliocene period, when they were incorporated in the almost fresh Pontian Lake-Sea. In modern times, the Black Sea remained connected with the Sea of Azov via the Kerch Strait and after construction of the Volga-Don Canal in 1952 all three seas were artificially reunited again. As a result, both native and invasive species from the Black Sea enter and established (due to similar environmental conditions) in the Caspian Sea, shaping its ecosystem. Therefore, it is important to compare the variability of abiotic parameters in these seas. The Black Sea is also a part of the Mediterranean basin, connected with it through the Bosporus Strait, the Sea of Marmara and the Dardanelles Strait (Figure 1).

Recent climate change pronouncedly shapes the Ponto-Caspian Seas ecosystem. In this regard, since the abiotic environmental factors (air and water temperature, wind, humidity of the atmosphere) strongly impact the ecosystem, the study of their variability is the first-priority issue.

Long-term variability of the surface air temperature (SAT) and sea surface temperature (SST) in the Black Sea in 1950–2005, associated with the local wind regime (which, in turn is governed by the large-scale atmospheric oscillations) has been studied in a number of research (e.g., Kazmin and Zatsepin, 2007; Kazmin et al., 2010; Kontoyiannis et al., 2012). In contrast to the quasi-regular decadal oscillations of the SST, typical for the Northern Atlantic, the authors described the pattern of the long-term SST variability in the Black Sea as an intermittent periods of SST increase/decrees with the duration of approximately 6–10 years and short (1–2 years) and quite abrupt transitions between them.

Recently, Ginzburg with co-authors calculated linear trends of hydrometeorological parameters in the Black Sea for 1980–2020 (Ginzburg et al., 2021) and showed that compare to an increase of SAT over the Black-Azov Sea region (+0.053 °C/year in 1980–2020) and SST in the Black Sea (+0.052 °C/year in 1982–2020), the values of these parameters in the 2000s noticeably differ from those in the 1980s–1990s: the maximum average monthly summer and minimum average monthly winter temperatures have increased, and the number of mild winters has increased. An average annual SST of the Black Sea, which did not exceed 15 °C in the 1980s – early 1990s, has exceeded 16 °C since 2010 (with the maximum of 16.71 °C in 2018).

The linear trends of a few abiotic parameters in the Caspian Sea over a relatively short time period (15–25 years) have been studied by Ginzburg with coauthors (Ginzburg, Kostianoy, Sheremet, 2004; Ginzburg, Kostianoy, Sheremet, 2005; Ginzburg, Kostianoy, Sheremet, 2012; Ginzburg and Kostianoy, 2018a; Ginzburg and Kostianoy, 2018b; Kostianoy et al., 2019). However, those works were limited by interannual variability and linear trends estimations, without addressing the issues of nonlinear decadal (not to mention multidecadal) changes.

Nonlinear inter-decadal climatic changes in the Black Sea-Caspian region and their relationship with variations of atmospheric circulation, North Atlantic and other oscillations were also considered in the works of Polonsky and Voskresenskaya with co-authors (e.g., Polonsky, 2013, 2015; Polonsky et al., 2013; Polonsky and Novikova, 2018; Kovalenko and Voskresenskaya, 2019 etc.).

Recently, an analysis of multidecadal variability of the hydrometeorological parameters (thermal, dynamic and associated with the moisture content of the atmosphere) in the Caspian Sea area for the period 1948–2017, based on polynomial approximation approach was performed by Kazmin (2021). Polynomial approximation analysis identified three main temporal intervals with an average duration of 10–25 years (1948–1964, 1972–1996, 2006–2017) with the multidirectional trends of parameters changes, which was considered as a manifestation of multidecadal variability (Kazmin, 2021).

The goal of the presented study is to compare the nonlinear multidecadal variability of hydro-meteorological parameters in the whole Ponto-Caspian region (Black, Azov and Caspian Sea) over a longer period (1948–2020). Reasonable assumption is that over such a long-time span (73 years), the parameters were not changed linearly, but followed periodic climate variations.

The main challenge of this study is to detect the time intervals of multidirectional trends of parameters changes within the considered time span (1948–2020) and provide comparative description (in geographical sense) of hydro-meteorological parameters variability in the closely located, but very different basins (Black and Caspian Seas).

2. Data and methods

The hydrometeorological parameters of the environment, considered in this work are divided into thermal (surface air temperature – SAT; sea surface temperature – SST), dynamic (zonal wind component – U; meridional wind component – V; wind speed module – $W = (U^2 + V^2)^{0.5}$) and parameters, associated with the moisture content of the atmosphere (relative humidity – RH, specific humidity – SH, precipitation rate – PR, and precipitable water – PW). The wind components are taken at the level of 1000 mb. The monthly-averaged values of the above-mentioned parameters for the period of 1948–2020 from NCEP/NCAR reanalysis dataset were obtained at NOAA/Physical Sciences Laboratory (https://psl.noaa.gov/cgi-bin/data/timeseries/timeseries1.pl). All atmospheric parameters were spatially averaged within the areas shown in Figure 1 (red boxes). SST values were spatially averaged for the deep-water parts of the basins taking into account the resolution of the source data (Figure 1, blue fill). Further, the monthly-mean values were averaged over the year and time series of annual values of the considered parameters for the period of 1948–2020 have been constructed. Exception is the SST, for which the reliable data are available only since 1982 (the beginning of the regular satellite measurements of SST). Further, polynomial approximations of 2–4 degrees were calculated for each time series. Degree of polynomial approximations was selected to highlight the gross features of long-term variability and is different for time series.

Fig. 1 – Study area. Red boxes – areas of spatial averaging of atmospheric parameters for the Black Sea and the Sea of Azov and Caspian Sea. Blue fill (deep-water parts of the Black and Caspian Seas basins) – areas of spatial averaging of SST

SST is one of the primary abiotic factors affecting the ecosystems, but as it was mentioned above, it is reliably available only since 1982. To extend the time span for assessment of thermal trends back to 1948, SAT is may be appropriate as a proxy for SST because of their close correlation. Earlier it was confirmed on an annual time scale for the Black Sea (correlation equal to 0.9; Kazmin et al., 2010) and for the Caspian Sea (correlation equal to 0.82; Kazmin, 2021).

Despite the seasonality of the region, we performed our analysis on the annual timescales, since the examination of seasonal differences indicated, that multidecadal variability of SAT is generally consistent across the year (Figures 2B and D and also Kazmin, 2021). Similar results have been obtained for the wind and moisture content of the atmosphere. Certainly, there are some seasonal discrepancies that should be analyzed in detail in the future. However, at the initial stage our goal was to highlight the gross features of multidecadal variability on the basin-wide and annual scales.

For the comparability of the results, the time series were normalized as follows: $P_{norm} = (P - \mu)/\sigma$, where P_{norm} is the normalized parameter, P is the original parameter, μ is the arithmetic mean of the distribution, and σ is the standard deviation of the distribution. Then, polynomial approximations were calculated for normalized time series.

To evaluate the statistical significance of obtained correlations, the null hypothesis was tested with Student's t-test. All correlation coefficients, presented in this study, are statistically significant with the probability level $p < 0.05$.

Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used to evaluate comparative performance of linear and polynomial models (see details in section 3.2).

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3. Data preprocessing

3.1. General patterns of multidecadal variability of abiotic parameters in the Ponto-Caspian seas in 1948–2020

Original unsmoothed time series of considered abiotic parameters with overlayed polynomial approximations of 2–4 degrees for the Black and Caspian seas are presented at Figure 2 and Figure 3 (thermal), Figure 4 (dynamic) and Figure 5 and Figure 6 (associated with the atmospheric moisture content).

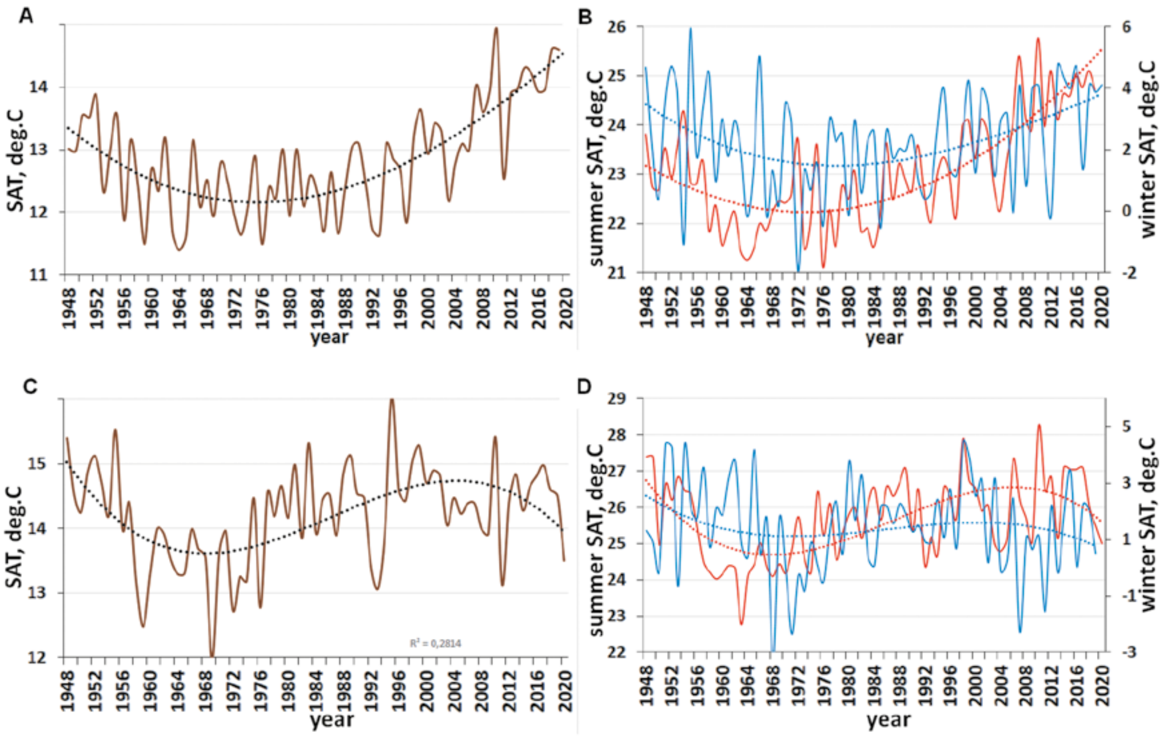

Fig. 2 – Original time series of annual-mean (left) and seasonally averaged for summer (red) and winter (blue) (right) values of SAT in the Black (**A**, **B**) and Caspian (**C**, **D**) seas. Dotted lines – polynomial approximations

Examination of seasonal differences (for SAT) indicated, that multidecadal variability are generally consistent across the year (Figures 2B and D). Thus, we performed further analysis on the annual timescales to obtain the gross features of multidecadal variability.

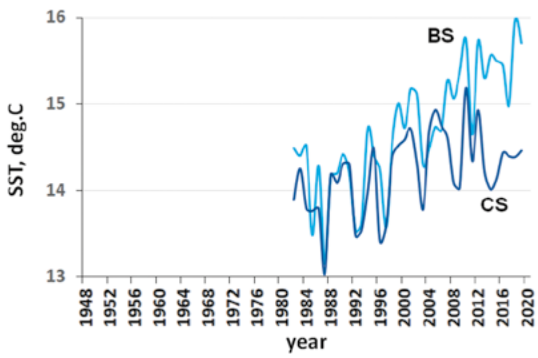

Fig. 3 – Original time series of annual-mean values of SST in the Black Sea (BS, blue line) and Caspian Sea (CS, deep blue line)

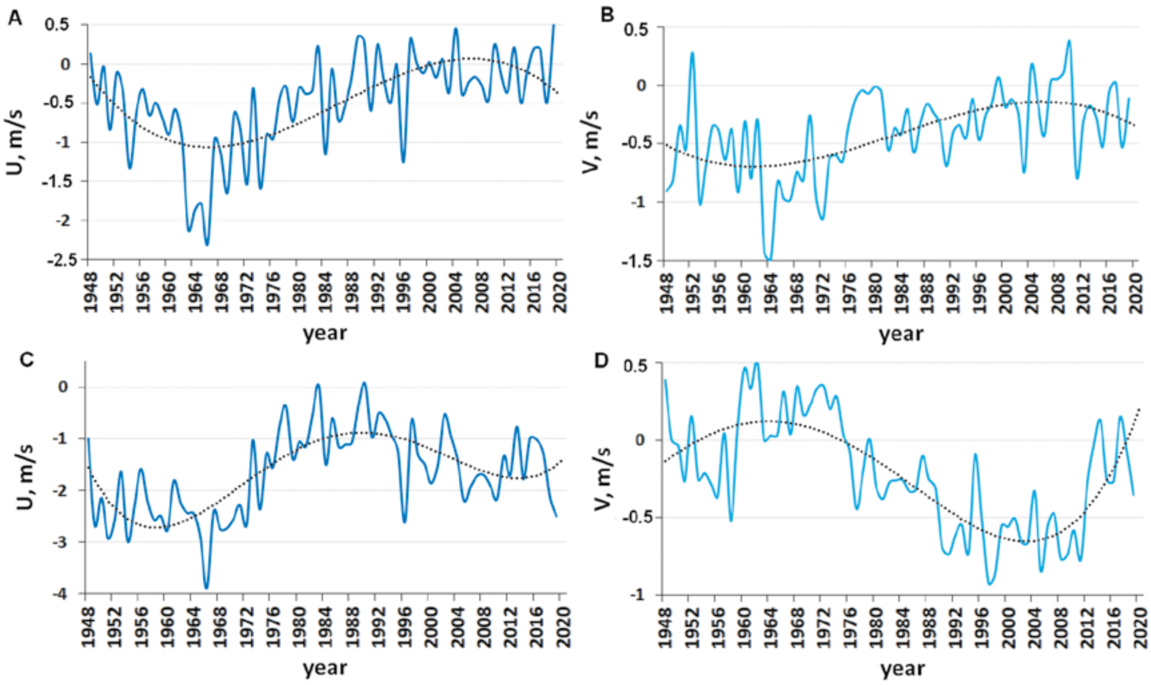

Fig. 4 – Original time series of annual-mean values of zonal wind components (left) and meridional wind components (right) in the Black (**A**, **B**) and Caspian (**C**, **D**) seas.
Dotted lines – polynomial approximations

These time series confirm the validity of the assumption about the non-linear nature of the hydrometeorological parameters variability. For comparison, we also calculated linear trends of mentioned parameters for the periods, used in the works by Ginzburg with co-authors (1980–2020 for the Black and 1982–2017 for the Caspian seas) (not shown). In order of magnitude, they are generally consistent with the above-cited results of Ginzburg with co-authors (Ginzburg, Kostianoy, Sheremet, 2004; Ginzburg, Kostianoy, Sheremet, 2005; Ginzburg, Kostianoy, Sheremet, 2012; Kostianoy et al., 2014; Ginzburg and Kostianoy, 2018a; Ginzburg and Kostianoy, 2018b; Kostianoy et al., 2019; Ginzburg et al., 2021) and our previous results (Kazmin, 2021).

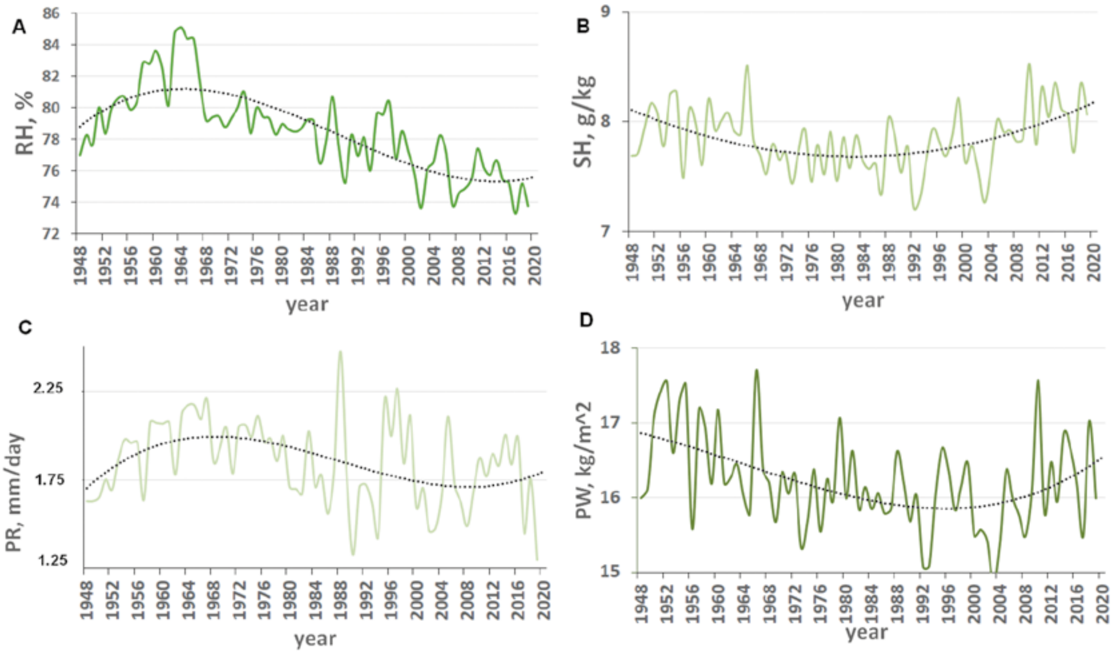

Fig. 5 – Original time series of annual-mean values of atmospheric moisture content parameters in the Black Sea. **A** – relative humidity, **B** – specific humidity, **C** – precipitation rate, **D** – precipitable water. Dotted lines – polynomial approximations

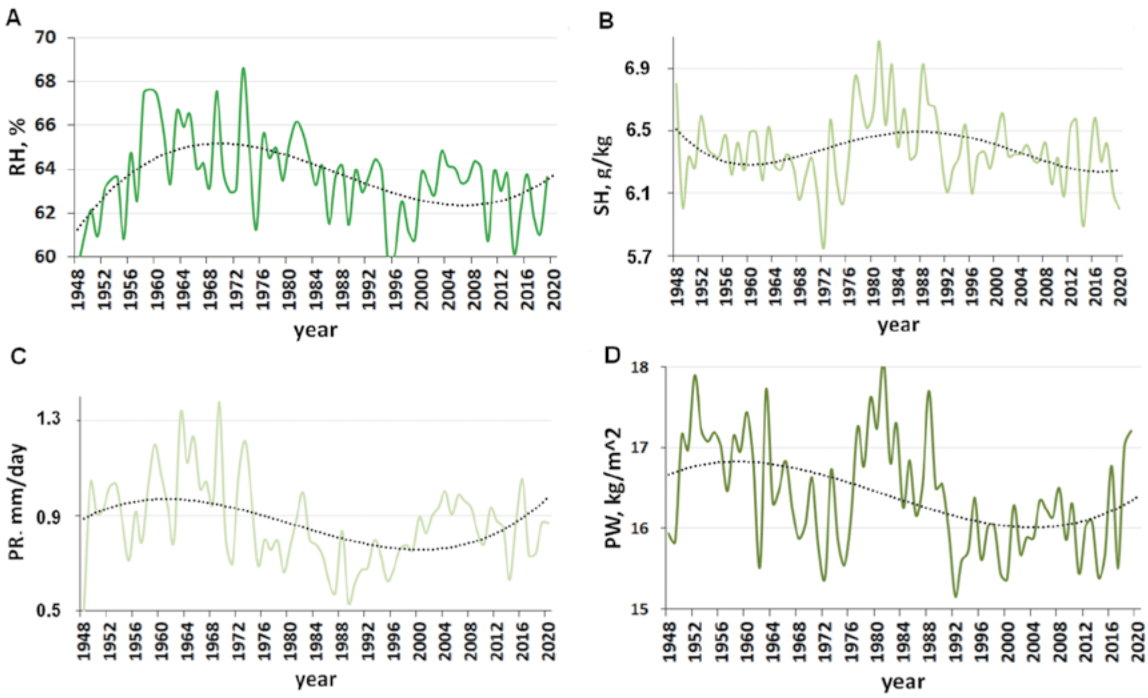

Fig. 6 – Original time series of annual-mean values of atmospheric moisture content parameters in the Caspian Sea. **A** – relative humidity, **B** – specific humidity, **C** – precipitation rate, **D** – precipitable water. Dotted lines – polynomial approximations

Polynomial approximations of the normalized time series (Figure 7) confirm the non-linear character of the multidecadal variability of the considered parameters. However, the patterns of variability are significantly different in the Black and Caspian seas.

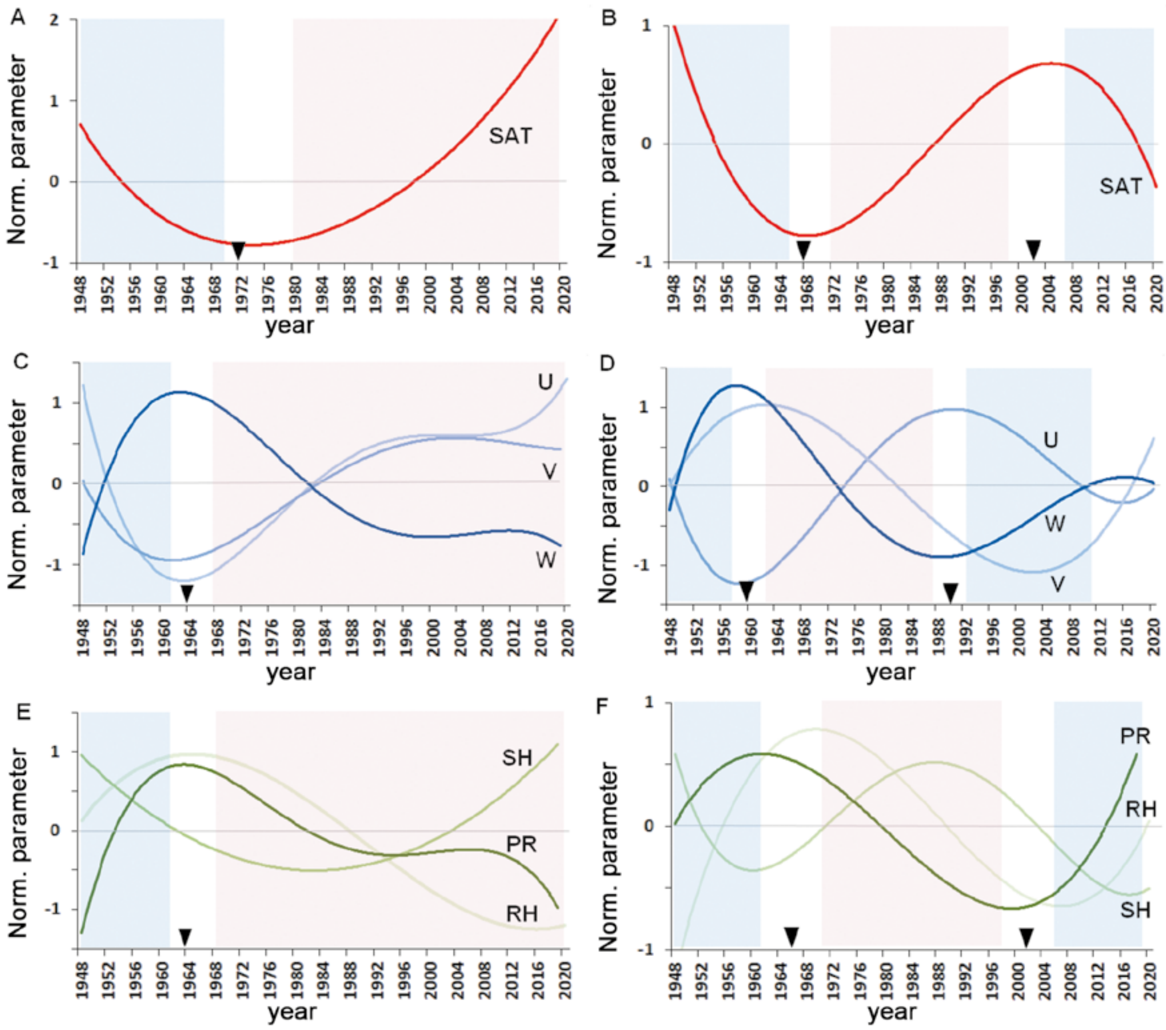

Fig. 7 – Polynomial approximations of normalized time series of hydrometeorological parameters in the Black (left) and Caspian (right) seas: (**A**, **B**) – thermal (SAT); (**C**, **D**) – dynamic (U, V, W,); (D, E) – related to atmospheric moisture content (RH, SH, PR). Colored rectangular fill marks the periods of the corresponding parameters increase/decrease. Black triangles at the abscissa axis mark the years of highs/lows of the corresponding parameters

Black Sea

In the Black Sea two temporal intervals of an average duration of 20 and 40 years with multidirectional trends of hydrometeorological parameters changes have been detected (Figure 7A). Thus, SAT decreased in 1948–1968 and raised in 1980–2020. Minimum of SAT values, marked with the black triangle at the abscissa axis (Figure 7A), were observed around 1972.

As for the dynamic parameters, U and V weakened, and W increased in 1948–1964 (Figure 7C). Opposite trends were observed after 1968 with U and V strengthening and W decreasing till 1996. After that, till the end of observational period, all dynamic parameters changed insignificantly, practically remaining constant (Figure 7C).

The values of parameters, related to atmospheric moisture content (RH and PR) increased in 1948–1962 and decreased after 1968 till the end of observational period. However, SH pattern was different (decrease in 1948–1978 and increase in 1984–2020) (Figure 7E).

Caspian Sea

In the Caspian Sea, unlike the Black Sea, three temporal intervals of average duration of 10–25 years with multidirectional trends of hydrometeorological parameters changes are detected. Thus, the SAT decreased in the period of 1948–1965, increased in 1972–1998, and decreased again in 2006–2020 (Figure 7B). Minimum and maximum of SAT values, marked with the black triangles at the abscissa axis (Figure 7B), were observed around 1968 and 2002, respectively.

As for the dynamic parameters, V and W increased, and U weakened in 1948–1958 (Figure 7D). Further, in 1962–1988, opposite trends of V and W weakening and U strengthening were observed (V weakening lasted till 1996). These trends were again reversed (V and W strengthening and U weakening) in 1994–2012 (V strengthening started later, in 2004 and continued until the end of the observation period). This is consistent with positive trend of W, calculated in Kostianoy et al. (2014) for 1979–2011. The highs/lows of U and W were recorded around 1960 and 1990 and that of V – around 1960 and 2002.

The values of parameters, related to atmospheric moisture content (except specific humidity) increased, decreased, and increased again in 1948–1965, 1972–1998, and 2005–2017, respectively (Figure 7F). The specific humidity (SH) changed in the opposite way. Highs/lows of RH and PR were observed around 1965 and 2002. Low/high of SH took place around 1961 and 1992.

One of the remarkable results of observational analysis is that the shift of the dynamic regime both in the Black and Caspian seas occurred earlier than the shift of the thermal and humidity regimes (Figure 7, black triangles at the abscissa axes). On average, the lag between zonal component of the wind and air temperature and humidity parameters is 6–8 years. This suggests a leading role of climatic variations of the large-scale atmospheric forcing in the regional variability of thermal and humidity parameters. For the Caspian Sea it was already reliably confirmed, using both the NCEP/NCAR and 20th Century Reanalysis data (Kazmin, 2021).

3.2. Performance of linear and polynomial models

Since the conclusions, presented in this paper are based on polynomial approximations of time series, it is reasonable to confirm that this approach is definitively better than the linear trends, used in previous studies. As an unbiased estimator of the fit of polynomials relative to linear model, the Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used. The AIC and BIC are the estimators of out-of-sample prediction error and thereby relative quality of statistical models for a given set of data. Given a collection of models for the data, AIC/BIC estimates the quality of each model, relative to each of the other models. Thus, AIC/BIC provides a means for model selection. A lower AIC/BIC value indicates a better fit. Table contains the values of AIC and BIC for linear and polynomial approximations. For all considered time series (except precipitable water) both criteria are less for polynomials, which proves that polynomials provide better fit to observations relative to linear model.

Table. Akaike information criterion (**AIC**) and Bayesian information criterion (**BIC**) for linear and polynomial approximations of time series in the Black and Caspian seas. Pink/blue fill marks higher/lower values of criterion

Criterion	Approximation	**SAT**	**U**	**V**	**W**	**RH**	**SH**	**PR**	**PW**
Black Sea									
AIC	Linear	202.4	194.3	198.1	190.0	201.3	198.8	181.9	186.9
	Polynomial	174.0	125.8	142.9	141.2	178.7	194.8	175.2	189.1
BIC	Linear	203.9	200.8	202.6	199.5	202.8	206.3	189.3	190.4
	Polynomial	182.0	138.1	153.1	150.5	187.7	200.8	185.0	195.2
Caspian Sea									
AIC	Linear	200.4	195.3	197.1	194.0	200.3	200.8	182.9	184.9
	Polynomial	175.0	127.8	144.9	140.2	180.7	193.8	177.2	186.1
BIC	Linear	204.9	199.8	201.6	198.5	204.8	205.3	187.3	189.4
	Polynomial	184.0	139.1	156.1	151.5	189.7	202.8	186.0	197.2

4. Results and discussion

4.1. Multidecadal variability of the wind regime and associated air temperature changes in the Black and Caspian Seas

Black Sea

Over the Black Sea area, with annual averaging, the North-Eastern atmospheric transport regime prevails, with the zonal component of the wind exceeding the meridional one by about two times. In more detail, the relationship between the zonal and meridional components of wind during the air temperature increase/decrease phases in the Black Sea is shown in Figure 8A. This illustration indicates that air temperature rise coincides with the weakening of both zonal (Eastern) and meridional (Northern) wind components. The opposite situation is observed during the phase of air cooling (zonal and meridional transport increase).

Since wind components act unidirectionally (air temperature rise/cooling coincides with the weakening/strengthening of both components), it is reasonable to use wind speed (W) for correlation with air temperature. The relationship between W and the air temperature over the Black Sea is shown in Figure 9A, which clearly demonstrates that during periods of cooling, the temperature decrease is associated with an increase of wind speed. During the warming phase, on the contrary, the temperature rises due to the weakening of wind speed.

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Caspian Sea

Over the Caspian Sea area, with annual averaging, the North-Eastern atmospheric transport regime also prevails, with the zonal component of the wind exceeding the meridional one by about five times. Relationship between the zonal and meridional components of wind during the air temperature increase/decrease phases in the Caspian Sea is shown in Figure 8B. However, unlike the Black Sea, in the Caspian Sea an increase of air temperature coincides with the weakening of zonal (Eastern) wind component and simultaneous intensification of meridional (Northern) component. The opposite situation is observed during the phase of air cooling (zonal transport increases, and meridional one weakens). This observation requires additional comments. If the connection of air warming/cooling with the weakening/strengthening of the zonal transport of cold air masses from Central Eurasia is quite obvious, then the strengthening/weakening of the Northern meridional transport during periods of warming/cooling seems to contradict the logic (according to which the strengthening/weakening of the meridional transport of cold air masses from the North should lead to cooling/warming). This discrepancy can be explained by taking into account that advective heat transport is proportional to wind speed and the horizontal gradient of air temperature. The spatial distribution of the annual average climatological air temperature in the part of Central Eurasia adjacent to the Caspian Sea, from which advective heat transport occurs (https://cdn.mapmania.org/original/detailed_map_of_annual_average_temperature_around_the_world_78684.jpg), shows that zonal air temperature gradient here significantly exceeds the meridional one. Approximate estimates indicate that the zonal gradient is about 7 °C/1000 km, while the meridional gradient is only 2 °C/1000 km. Taking into account that also the velocity of zonal transport exceeds the velocity of meridional transport in about five times, we can talk about the leading role of zonal (Eastern) transport in the heat advection to the Caspian Sea area. The opposite thermal effect of meridional transport is simply absorbed by the prevailing impact of zonal transport.

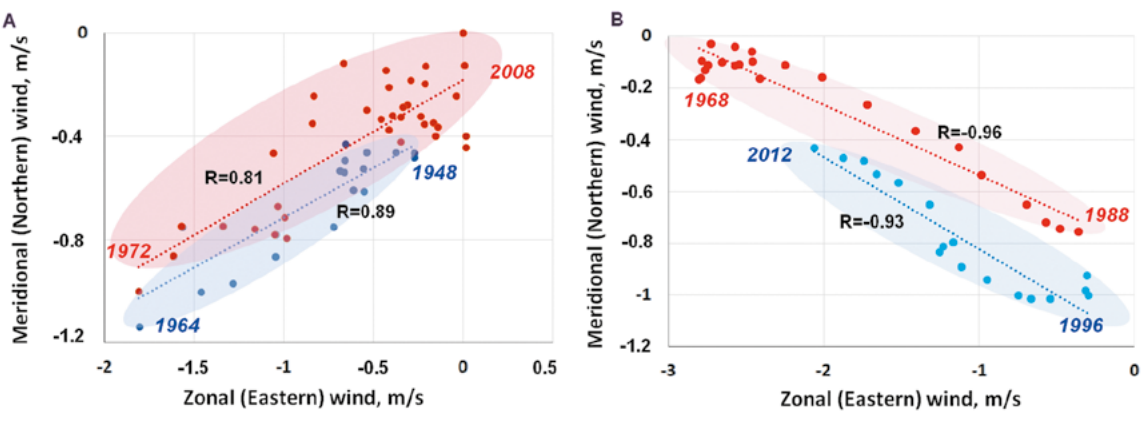

Fig. 8 – Correlations between zonal (U) and meridional (V) wind components in the Black (**A**) and Caspian (**B**) Seas. Blue/red dots and blue/pink fill indicate periods of SAT decrease/increase (1948–1964/1972–2008 for the Black Sea and 1996–2012/1968–1988 for the Caspian Sea). Dotted lines – linear regressions. R – correlation coefficients

The relationship between the zonal component of wind and the air temperature over the Caspian Sea is shown in Figure 9B, which clearly demonstrates that during periods of cooling, the temperature decrease is associated with an increase of zonal (Eastern) transport. During the warming phase, on the contrary, the temperature increases due to the weakening of zonal transport.

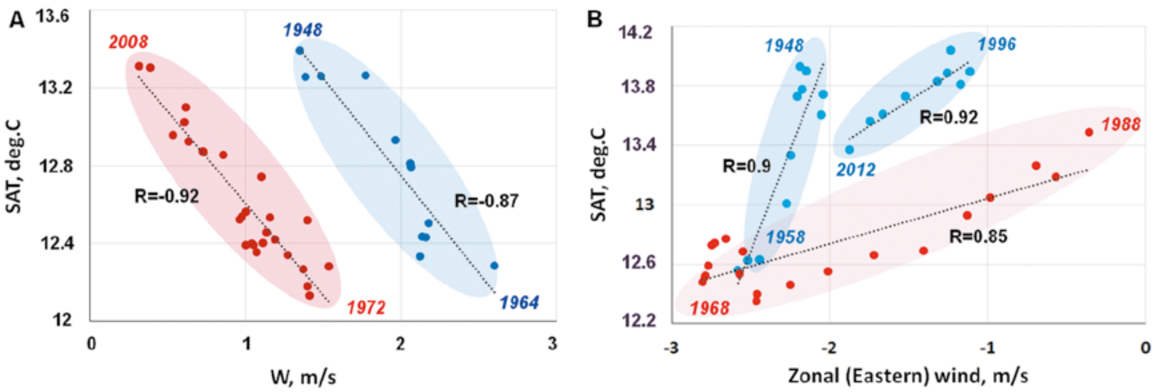

Fig. 9 – Correlations between wind speed (W) and air temperature (SAT) during periods of cooling (1948–1964) and warming (1972–2008) in the Black Sea (**A**). Correlations between zonal wind component (U) and air temperature (SAT) during periods of cooling (1948–1958, 1996–2012) and warming (1968–1988) in the Caspian Sea (**B**). Blue/red dots and blue/pink fill indicate periods of SAT decrease/increase. Dotted lines – linear regressions. R – correlation coefficients

4.2. Multidecadal variability of the air temperature and atmospheric moisture content in the Black and Caspian Seas

Further, the relationships between the long-term variability of atmospheric moisture content parameters and air temperature were addressed in brief. Specific humidity, which is the absolute mass of water vapor per unit mass of air regardless of its temperature, is one of the most important humidity characteristics. Specific humidity is positively correlated (R = 0.8 in the Black Sea and R = 0.75 in Caspian) with air temperature and decreases/increases during periods of cooling/warming (Figures 7E and F). Since the specific humidity itself does not depend on the air temperature, its change can occur due to evaporation from the water surface or advective transport. Considering that during the periods of specific humidity increase/decrease (warming/cooling, respectively) zonal transport weakened/increased, the main factor of specific humidity variability should be evaporation from the sea surface. Thus, it can be assumed that an increase of air temperature causes intensified evaporation and an observed rise of specific humidity, and vice versa.

Relative humidity is the ratio of the partial pressure of water vapor in the air to the equilibrium pressure of saturated vapor at a given temperature. The relative humidity depends on the air temperature – at given specific humidity, the relative humidity will be lower for warm air and higher for cold air. This explains the observed negative correlation (R = –0.75 in the Black Sea and R = –0.81 in the Caspian) between air temperature and relative humidity

(Figures 7A, B, E and F). During the periods of cooling/warming there is an increase/decrease of relative humidity.

The precipitation rate was also negatively correlated with air temperature (R = –0.81 in the Black Sea and R = –0.94 in the Caspian Sea). It increased during the periods of cooling and decreased during the periods of warming (Figures 7A, B, E and F). The precipitation rate is the result of complex interaction of a number of factors and cannot be analyzed in detail in this work.

The precipitable water, which is the mass of water vapor in a column of air of a unit area from the surface to the upper boundary of the atmosphere, behaves similarly to relative humidity: it increases during cooling periods and decreases during warming. However, no statistically significant correlation between variations of precipitable water and air temperature was found. In part, this can be explained by the fact that the polynomial approximation of this parameter demonstrates a worse result relative to the linear trend (higher values of AIC/BIC for polynomial; Table).

4.3. Possible impact of the large-scale atmospheric forcing upon the wind regime in the Ponto-Caspian area

In the context of this study, the relationship of the observed multidecadal variability of hydrometeorological parameters with the large-scale atmospheric processes is of interest. However, the issue is complicated and could provide the subject for another full-scale research. In this regard, we presented here only some debatable assumptions, based on qualitative phenomenological analysis.

Large-scale atmospheric processes, potentially affecting the long-term variability of regional wind regime over the Ponto-Caspian area can be the North Atlantic Oscillation (NAO) and the East Atlantic-West Russian pattern (EAWR). NAO is associated with fluctuations in the atmospheric pressure difference between the Icelandic minimum and the Azores maximum in the North Atlantic and can affect the intensity of western atmospheric transport over Europe up to the Eastern Mediterranean and the Caspian region. The EAWR oscillation system is comprised by two centers of anomalous atmospheric pressure over the Caspian Sea and Western Europe and governs the North-Eastern transport regime in the region under consideration (Barnston, Livezey, 1987). There are a number of studies on the behavior of atmospheric processes at various combinations of NAO and EAWR intensity. In particular, the weakening of the NAO (NAO index <0) combined with the strengthening of the EAWR (EAWR index >0) provides conditions for the intensification of North-Eastern transport (Krichak et al., 2002; Kutiel, Benaroch, 2002). It is exactly the situation that we observed during the periods of Eastern transport intensification (and, consequently, cooling) over the Caspian Sea in 1948–1958 and 1994–2010: the NAO index decreased to negative (1948–1958) or zero (1994–2010) values, while the EAWR index was significantly positive. On the contrary, during the easing of the Eastern transport (warming) in 1968–1988, there was a sharp increase of the NAO index, coinciding with the strongly negative values of the EAWR index (Figures 10A, B and C).

As for the Black Sea, the situation is controversial: the general pattern of variability in 1948–1992 was similar to that for the Caspian Sea with North-Eastern transport strengthening/weakening in 1948–1965/1970–1990, and consistent with described combinations of NAO and EAWR. However, after 1992 no pronounced trend in variability of North-Eastern transport have been observed (Figures 7C, 10D).

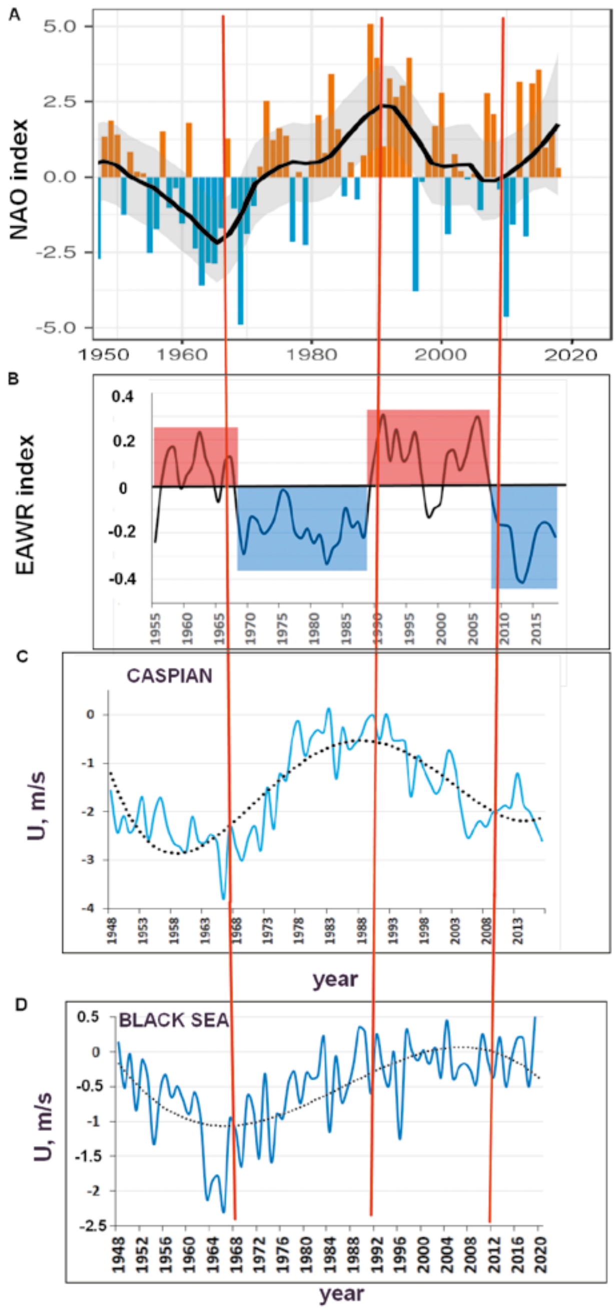

Fig. 10 – Long-term variability of NAO index (**A**; https://en.wikipedia.org/wiki/North_Atlantic_oscillation#/media/File:Winter-NAO-Index.svg, modified by the authors), EAWR index (**B**) and the zonal wind component U (**C** – Caspian, **D** –Black Sea).
Orange/blue bars at the **A** panel indicates positive/negative values of the NAO.
Red/blue fill in the **B** panel indicates periods of positive/negative values of the EAWR index.
Vertical red lines mark the years of minimum and maximum values of the NAO index

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5. Conclusions

This study addressed a crucial problem of exploring the variability of basic abiotic environmental factors, which may affect the marine ecosystems of the Ponto-Caspian seas. Analysis of the multidecadal variability of hydrometeorological parameters (thermal, dynamic and associated with the moisture content of the atmosphere) in the Black and Caspian seas areas for the period 1948–2020, based on polynomial approximation approach was performed. Test with unbiased estimators (AIC/BIC metrics) confirms that polynomials provide a definitively better fit to observed time series relative to the linear model, used in previous studies.

We argue that closely located geographically, but essentially different basins of the Black and Caspian seas reveal different patterns of long-term variability of hydrometeorological parameters. Polynomial approximations allowed to distinguish in the Black Sea two temporal intervals of an average duration of 20 and 40 years with multidirectional trends of hydrometeorological parameters changes, while in the Caspian Sea three such intervals lasting 10–25 years are identified, which is considered as a manifestation of multidecadal variability.

Under annual averaging, the North-Eastern wind regime prevails over the both basins. However, if in the Black Sea wind components act unidirectionally (air temperature rise/cooling coincides with the weakening/strengthening of both components), then in Caspian they act the opposite way. Phases of air warming/cooling in the Caspian Sea coincide with a weakening/strengthening of the Eastern wind transport since the zonal wind speed and horizontal air temperature gradient significantly exceed meridional ones. In the Black Sea warming/cooling coincide with a weakening/strengthening of the wind speed, since both wind component provide the same effect.

Noteworthy result of observational analysis is that the shift of the dynamic regime in both seas occurred 6–8 years earlier than the shift of the thermal and humidity regimes. This suggests a leading role of climatic variations of the large-scale dynamic atmospheric forcing in the variability of thermal and humidity parameters in the Black and Caspian Sea.

In regard to parameters, associated with the moisture content of the atmosphere, it was found that both in the Black and in the Caspian seas specific humidity is positively correlated with air temperature and its decrease/increase coincide with phases of cooling/warming. In contrast, relative humidity and precipitation rate variations are negatively correlated with air temperature tendencies.

As for an impact of the large-scale atmospheric processes on regional wind regime, qualitative observational results indicate that intensification of Eastern transport (and, consequently, cooling) over the Caspian Sea coincides with a situation when the NAO index decreases to negative or zero values, while the EAWR index is significantly positive. On the contrary, weakening of the Eastern transport (and warming) occurs during a period of sharp strengthening of the NAO coinciding with strongly negative values of the EAWR index. In the Black Sea the situation is controversial: the general pattern of variability in 1948–1992 was similar to that in the Caspian Sea and consistent with described combinations of NAO and EAWR. However, after 1992 no pronounced trend in variability of North-Eastern transport have been observed.

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References

1. Dobrovolskii, A. D. and B. S. Zalogin, 1982: *Seas of the USSR*. Moscow, Moscow State University Publishing, 192 p. [in Russian].
2. Ginzburg, A. I., A. G. Kostianoy, and N. A. Sheremet, 2004: Seasonal and interannual variability of the surface temperature in the Caspian Sea. *Oceanology*, **44** (5), 605–618.
3. Ginzburg, A. I., A. G. Kostianoy, and N. A. Sheremet, 2005: Sea Surface Temperature Variability. The Caspian Sea Environment. Kostianoy A. G. and Kosarev A. N. (Eds.), The Handbook of Environmental Chemistry, Springer-Verlag GmbH, **5**, 59–81.
4. Ginzburg, A. I., A. G. Kostianoy, and N. A. Sheremet, 2012: Long-term variability of the surface temperature of Caspian Sea (1982–2009). *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, **9** (2), 262–269 [in Russian].
5. Ginzburg, A. I. and A. G. Kostianoy, 2018a: Interannual variability of the Caspian Sea surface temperature in the current period (2003–2017). *Vestnik Tverskogo universiteta,* Seriya "Geografiya i geoekologiya", **3**, 57–65 [in Russian].
6. Ginzburg, A. I. and A. G. Kostianoy, 2018b: Tendencies of changes in hydrometeorological parameters of the Caspian Sea in the modern period (1990s–2017). *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, **15**, 195–207, https://doi.org/10.21046/2070-7401-2018-15-7-195-207 [in Russian].
7. Ginzburg, A. I., A. G. Kostianoy, I. V. Serykh, and S. A. Lebedev, 2021: Climatic Changes in Hydrometeorological Parameters of the Black and Azov Seas (1980–2020). *Oceanology*, **61** (6), 900–912.
8. Kazmin, A. S., 2021: *Multidecadal variability of the hydrometeorological parameters in the Caspian Sea. Estuarine, Coastal and Shelf Science.* **250**, 107150, https://doi.org/10.1016/j.ecss.2020.107150.
9. Kazmin, A. S. and A. G. Zatsepin, 2007: Long-term variability of surface temperature in the Black Sea, and its connection with the large-scale atmospheric forcing. *J. Mar. Syst.,* **68**, 293–301.
10. Kazmin, A. S., A. G. Zatsepin, and H. Kontoyiannis, 2010: Comparative analysis of the long-term variability of winter surface temperature in the Black and Aegean Seas during 1982–2004 associated with large scale atmospheric forcing. *Int. Journal of Climatology*, **30**, 1349–1359.
11. Kontoyiannis, H., V. Papadopulos, A. Kazmin, A. Zatsepin, and D. Georgopulos, 2012: Climatic variability of the sub-surface sea temperatures in the Aegean-Black Sea system and relation to meteorological forcing. *Clim. Dyn.*, **39** (6), 1507–1525.

12. Kostianoy, A. G., A. I. Ginzburg, S. A. Lebedev, and N. A. Sheremet, 2014: *Southern seas of Russia. Second assessment report of Roshydromet on climate change and its consequences on the territory of the Russian Federation. Federal service for Hydrometeorology and environmental monitoring (Roshydromet).* Kattsov V. M., Semenov S. M. (Eds.), Moscow, FGBU "IGKE Rosgidrometa i RAN", 644–683 [in Russian].
13. Kostianoy, A. G., A. I. Ginzburg, O. Y. Lavrova, S. A. Lebedev, M. I. Mityagina, N. A. Sheremet, and D. M. Soloviev, 2019: Comprehensive Satellite Monitoring of Caspian Sea Conditions. Barale V. and Gade M. (Eds.). *Remote Sensing of the Asian Sea*, Springer, Cham, 505–521.
14. Kovalenko, O. Yu. and E. N. Voskresenskaya, 2019: The decadal-multidecadal changes of extreme air temperature in the Black Sea region. *IOP Conference Series: Earth and Environmental Science*, **272**, https://doi.org/10.1088/1755-1315/272/2/022183.
15. Polonsky, A. B., 2013: *Large-scale ocean-atmosphere interaction and its impact on global and regional climate variability*. Kyev, Akademperiodica, 126 p.
16. Polonsky, A. B., 2015: *Oceans, global warming hiatus and regional climate variability (Global and regional climate change, atmospheric and marine variability in the Black Sea region).* Germany, Lambert Academic Publishing Saarbrucken, 192 p.
17. Polonsky, A. B., I. G. Shokurova, and V. N. Belokopytov, 2013: Ten-year variability of temperature and salinity in the Black Sea. *Morskoy Gidrofizicheckiy Zhurnal*, **6**, 27–41 [in Russian].
18. Polonsky, A. B. and A. M. Novikova, 2018: Inter-decadal variability of surface temperature and cold intermediate layer in the Black Sea. *Environmental control systems,* **4** (34), 110–115, https://doi.org/10.33075/2220-5861-2018-4-110-115.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ МУЛЬТИДЕКАДНОЙ ИЗМЕНЧИВОСТИ ГИДРОМЕТЕОРОЛОГИЧЕСКИХ ПАРАМЕТРОВ В ПОНТО-КАСПИЙСКИХ МОРЯХ

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Данные реанализа NCEP/NCAR за 1948–2020 гг. использованы для исследования многодекадной изменчивости гидрометеорологических параметров (тепловых, динамических и влажностных) в Понто-Каспийском регионе (Черное, Азовское и Каспийское моря). Полиномиальные аппроксимации временных рядов среднегодовых значений указывают на нелинейный характер и периодичность долгосрочной изменчивости рассматриваемых параметров. Будучи географически близко расположенными, эти моря демонстрируют совершенно разные модели изменчивости. В Черном море обнаружены два временных интервала средней продолжительностью 20 и 40 лет с разнонаправленными тенденциями изменения гидрометеорологических параметров, в то время как в Каспийском море выявлены три таких интервала продолжительностью

10–25 лет. В обоих бассейнах преобладает северо-восточный ветровой режим. Однако, если в Черном море ветровые компоненты действуют однонаправленно (повышение/охлаждение температуры воздуха совпадает с ослаблением/усилением обоих компонентов), то на Каспии они действуют противоположным образом, причем большая часть адвекции тепла осуществляется зональным (восточным) переносом. Фазы потепления/охлаждения воздуха совпадают с ослаблением/усилением этого переноса. Временной лаг между изменением динамического и теплового режимов (а также влажности) составляет около 6–8 лет, что свидетельствует о ведущей роли крупномасштабных изменений атмосферного воздействия. Колебания относительной влажности и количества осадков отрицательно коррелированы с изменением температуры воздуха. Над Каспийским морем интенсификация восточного переноса и связанное с этим похолодание совпадают с ситуацией, когда индекс Северо-Атлантического колебания (САО) уменьшается до отрицательных значений, а индекс Восточно-Атлантического – Западно-Русского (ВАЗР) колебания является положительным. Напротив, ослабление восточного переноса и потепление происходят в периоды резкого усиления САО, совпадающего с отрицательными значениями индекса ВАЗР. Что касается Черного моря, то ситуация противоречива: общая картина изменчивости в 1948–1992 годах была аналогична таковой в Каспийском море и соответствовала описанным комбинациям индексов. Однако после 1992 года не наблюдалось никакой выраженной тенденции в изменчивости северо-восточного переноса.

Ключевые слова: мультидекадная изменчивость, температура воздуха, температура поверхности воды, ветровой режим, влажность атмосферы, Понто-Каспийские моря

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Список литературы

1. *Гинзбург А. И., Костяной А. Г., Шеремет Н. А.* Долговременная изменчивость температуры поверхности Каспийского моря // Современные проблемы дистанционного зондирования Земли из космоса. 2012. Т. 9. № 2. С. 262–269.
2. *Гинзбург А. И., Костяной А. Г.* Межгодовая изменчивость температуры поверхности Каспийского моря // Вестник Тверского Университета. Серия «География и геоэкология». 2018a. № 3. С. 57–65.
3. *Гинзбург А. И., Костяной А. Г.* Тенденции изменений гидрометеорологических параметров Каспийского моря в современный период (1990-е–2017 гг.) // Современные проблемы дистанционного зондирования Земли из космоса. М., 2018b. Т. 15. № 7. С. 195–207. https://doi.org/10.21046/2070-7401-2018-15-7-195-207.
4. *Добровольский А. Д., Залогин Б. С.* Моря СССР. М.: Издательство Московского Государственного Университета, 1982. 192 с.
5. *Костяной А. Г., Гинзбург А. И., Лебедев С. А., Шеремет Н. А.* Южные моря России. Второй оценочный отчет Росгидромета о климатических изменениях и их последствиях на территории Российской Федерации. Федеральная служба гидрометеорологии и мониторинга среды (Росгидромет) / Под ред. В. М. Катсов, С. М. Семенов. Москва: ФГБУ «Росгидромета и РАН», 2014. С. 644–683.

6. *Ginzburg A. I., Kostianoy A. G., Sheremet N. A.* Seasonal and interannual variability of the surface temperature in the Caspian Sea // Oceanology. 2004. Vol. 44 (5). P. 605–618.
7. *Ginzburg A. I., Kostianoy A. G., Sheremet N. A.* Sea Surface Temperature Variability. The Caspian Sea Environment. Kostianoy A. G. and Kosarev A. N. (Eds.) // The Handbook of Environmental Chemistry. Springer-Verlag GmbH, 2005. Vol. 5. P. 59–81.
8. *Ginzburg A. I., Kostianoy A. G., Serykh I. V., Lebedev S. A.* Climatic Changes in Hydrometeorological Parameters of the Black and Azov Seas (1980–2020) // Oceanology. 2021. Vol. 61 (6). P. 900–912.
9. *Kazmin A. S.* Multidecadal variability of the hydrometeorological parameters in the Caspian Sea // Estuarine, Coastal and Shelf Science. 2021. Vol. 250. https://doi.org/10.1016/j.ecss.2020.107150.
10. *Kazmin A. S., Zatsepin A. G.* Long-term variability of surface temperature in the Black Sea, and its connection with the large-scale atmospheric forcing // J. Mar. Syst. 2007. Vol. 68. P. 293–301.
11. *Kazmin A. S., Zatsepin A. G., Kontoyianis H.* Comparative analysis of the long-term variability of winter surface temperature in the Black and Aegean Seas during 1982–2004 associated with large scale atmospheric forcing // Int. Journal of Climatology. 2010. Vol. 30. P. 1349–1359.
12. *Kontoyiannis H., Papadopulos V., Kazmin A., Zatsepin A., Georgopulos D.* Climatic variability of the sub-surface sea temperatures in the Aegean-Black Sea system and relation to meteorological forcing // Clim. Dyn. 2012. Vol. 39. No. 6. P. 1507–1525.
13. *Kostianoy A. G., Ginzburg A. I., Lavrova O. Y., Lebedev S. A., Mityagina M. I., Sheremet N. A., Soloviev D. M.* Comprehensive Satellite Monitoring of Caspian Sea Conditions / Barale V. and Gade M. (Eds.). Remote Sensing of the Asian Sea. 2019. Springer, Cham, P. 505–521.
14. *Kovalenko O. Yu., Voskresenskaya E. N.*, 2019: The decadal-multidecadal changes of extreme air temperature in the Black Sea region. IOP Conference Series: Earth and Environmental Science, Vol. 272. https://doi.org/10.1088/1755-1315/272/2/022183.
15. *Polonsky A. B.* Large-scale ocean-atmosphere interaction and its impact on global and regional climate variability. Kyev: Akademperiodica, 2013. 126 p.
16. *Polonsky A. B.* Oceans, global warming hiatus and regional climate variability (Global and regional climate change, atmospheric and marine variability in the Black Sea region). Germany: Lambert Academic Publishing Saarbrucken, 2015. 192 p.
17. *Polonsky A. B., Shokurova I. G., Belokopytov V. N.* Ten-year variability of temperature and salinity in the Black Sea // Morskoy Gidrofizicheckiy Zhurnal. 2013. No. 6. P. 27–41 [in Russian].
18. *Polonsky A. B., Novikova A. M.* Inter-decadal variability of surface temperature and cold intermediate layer in the Black Sea // Environmental control systems. 2018. Vol. 4. No. 34. P. 110–115. https://doi.org/10.33075/2220-5861-2018-4-110-115.

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