The Decadal-Multidecadal Changes of Extreme Air Temperature in the Black Sea Region

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Abstract. The decadal-multidecadal changes of extreme air temperature characteristics during winter and summer in the Black Sea region are studied in the paper. The 5th and 95th percentiles of intra-seasonal daily temperature anomalies and number of days with air temperature below the 5th and above the 95th percentile were used to describe moderate extremes. The average daily air temperature data from 13 hydrometeorological stations in 1950–2014 and from several stations in 1900–2005 were analyzed. Pacific Decadal oscillation (PDO) and the Atlantic Multidecadal oscillation (AMO) were considered as the main global processes in the ocean-atmosphere system responsible for regional climate change on decadal-multidecadal scale. The differences of extreme air temperature characteristics between positive and negative AMO and PDO phases are analyzed in the paper. It is found that the extreme winter air temperature anomalies are increased by about 2 °C during the positive PDO phase and negative AMO phase. The winter frequency of extreme low temperature is decreased by two times during the positive PDO phase and negative AMO phase. The summer changes of extreme temperature characteristics, associated with the PDO and AMO phases are insignificant.

1. Introduction

The extreme air temperature is an important integral characteristic of climate change. Its influence covers all fields of human life (health, economic activity and environmental quality). During the 20th century, the frequency of extreme low temperatures is decreased and the frequency of extreme high temperatures is increased all over the Northern Hemisphere [1, 2]. These changes have a significant impact not only on the environmental conditions, but on the current characteristics of technical systems too. In part, climate change influences on buildings through change of hydrometeorological factors, as well as on energy consumption changes needed for their heating or cooling. In particular, author of model investigation [3], done for Zurich–Kloten, have shown that if air temperature during XXI century will increase, then annual cooling energy demand will increase by 223–1050% while the heating energy demand will fall by 36–58%. Study, published in [4], has found that the duration of the heating period in the second half of the 20th century decreased with the average rate of 3–4 days/10 years. This involves the increasing air temperature during that time period. Therefore, the study of such air temperature characteristics as upper and lower quantiles (or percentiles) has a great practical importance not only for human health, but for many branches of economic activity too.

According to the ROSHYDROMET report (2014), the engineering systems have a higher capacity to the observed climate changes [2]. The main measure of possible adaptations is prevention and
planning. It is possible only on the basis of climate change knowledge regularities predictor’s defense. The main predictors of observed global changes are the climate processes in the ocean-atmosphere system, such as the Pacific Decadal oscillation (PDO) and the Atlantic Multidecadal oscillation (AMO).

The Pacific Decadal oscillation is defined as the sea surface temperature (SST) anomaly in the Pacific area limited 20°–60° N on the time scale of about 20–30 years [e.g., 5]. It characterizes by two stable phases: negative and positive. Recently it is shown that the PDO phases change are accompanied by the cyclone trajectories shift [6], changes in the river runoff [7], variation in the extreme precipitation [8, 9].

The Atlantic Multidecadal oscillation is a quasi-periodic SST anomalies change over the North Atlantic basin with typical timescale from 50 to 100 years [10]. Its phases are accompanied by regional changes of the air temperatures [11], precipitation [12] and cyclone parameters [6] etc.

At the same time, regional manifestations of decadal-multidecadal processes in the extreme air temperature have not been sufficiently studied. Therefore, the aim of present paper is to analyze the changes of extreme air temperature characteristics in the Black Sea region, associated with the Pacific Decadal oscillation and the Atlantic Multidecadal oscillation.

2. Data and methods

Daily observations of the air temperature at 13 stations of the Black Sea region in 1950–2014 and several stations (Genichesk, Odessa, Simferopol, Sochi, Feodosiya) in 1900–2005 were collected from [13]. The geographical coordinates of analyzed stations are shown in the Table 1. The stations were selected using the following criterion: the number of passes should be less than 20% of time series length. Then, according to the criteria from [14], the quality control procedure of air temperature data has been done.

| Station  | WMO ID | Longitude (°E) | Latitude (°N) | Elevation (m) |
|----------|--------|----------------|---------------|--------------|
| Anapa    | 37001  | 37.33          | 44.90         | 30.0         |
| Armavir  | 37031  | 41.12          | 44.98         | 159.0        |
| Gelendzhik | 37004 | 38.08          | 44.56         | 14.0         |
| Henichesk | 33910 | 34.82          | 46.17         | 15.0         |
| Izmail   | 33889  | 28.85          | 45.37         | 28.0         |
| Kerch    | 33983  | 36.42          | 45.40         | 49.0         |
| Krasnodar | 34927 | 38.98          | 45.03         | 28.0         |
| Odessa   | 33837  | 30.77          | 46.43         | 42.0         |
| Rostov-on-Don | 34730 | 39.75          | 47.25         | 74.0         |
| Simferopol | 33946 | 34.12          | 44.96         | 181.0        |
| Sochi    | 37099  | 39.72          | 43.60         | 57.0         |
| Tuapse   | 37018  | 39.07          | 44.10         | 60.0         |
| Feodosiya | 33976 | 35.38          | 45.03         | 26.0         |

As a measure of climatic processes, the PDO and AMO indices, derived from [15], were used. The positive / negative value of the index corresponds to positive / negative phase of the climate process.

The following extreme air temperature characteristics have been calculated: the 5th (P5) and 95th (P95) percentiles of intra-seasonal daily air temperature anomalies, the number of days with air temperatures below the 5th (Q5) and above the 95th (Q95) percentile.

The temperature anomalies are calculated as deviations from the smoothed annual cycle. According to the obtained time series of air temperature anomalies, the 5th and 95th percentiles per each calendar season are identified. Previously, this approach was used in [16].
The number of days with air temperatures below the 5th and above the 95th percentile is calculated using the methodology developed by IPCC experts group on the extremes. However, there are differences in percentile values. IPCC experts have developed indices for the 10th and 90th percentile, while we used 5 and 95 percentiles in this study. The calculation procedure is as follows. The 5th and 95th percentiles of air temperature are calculated for each calendar day. Next, the air temperature in current day is compared with the corresponding percentile for calendar day. The number of days with the extreme air temperature is calculated as the sum of days if condition is fulfilled: the air temperature is below (above) than the 5th (95th) percentile.

The PDO and AMO manifestations in the extreme air temperature characteristics are studied using composite analysis. At first, the equal intervals of positive and negative AMO phase (1953–1965 and 1996–2012/1966–1995) and PDO phase (1977–2002 and 1951–1976) were determined. After ranking the values of indices in these periods, 20 months with extreme positive (negative) values in each season were selected. Then Q5 and Q95 for described above months for each station in the analyzed region were summarized. Further, the obtained sums were divided by the number of days with the availability data of air temperature in the same months. Thus, frequency of extreme low temperature (F5) and extreme high temperature (F95) for phases of climate processes were determined. Next, the difference between the samples (so-called difference composite) is calculated. The significance of composites is determined by the Pearson χ² criterion.

The changes in P5 and P95 of intra-seasonal air temperature anomalies, associated with PDO and AMO phases, were estimated as differences between the mean values. It is necessary to notice that climate process phases are divided for equal intervals.

3. Results

3.1. PDO

The PDO index change in 1910, 1947, 1977 was noted in [e.g., 6, 17–19]. Figure 1a demonstrates these variation. Some authors pointed out that the periods of positive / negative PDO phases correspond to the periods of warming / cooling in the Northern Hemisphere [20]. The analysis of time series of extreme air temperature anomalies and number of days with extremes at some Black Sea hydrometeorological stations in 1900-2005 showed significant changes in the mean values, depending on the PDO phase. For example, the time series and mean values, corresponded to the PDO phases, at Simferopol station are given in figure 1b. It was found that the mean values of winter P5 of air temperature anomalies after 1977 are increased. The maximum values of this characteristic difference are found in Northern, North-East of Crimea. It reaches 1.7 °C. The 1977 year is characterized by the change of PDO index sign and called as “global climate shift” [1]. It means that winter temperatures during the second part of the XX century became warmer. The summer P95 of air temperature anomalies after 1977 are increased. The maximum difference between mentioned composites is 0.3 °C. Their time series are not given in Figure 1.

Figure 1c demonstrates an increasing of Q5 in winter from the beginning to the mid of XX century. But the Q95 in summer is increased between the end of the 20th and the beginning XXI century (figure 1d). This is consistent with the estimates of the IPCC report [1], which were obtained for the Northern Hemisphere entire. The maximum change of Q5 and Q95 are observed after 1976/1977, during PDO positive phase. The difference composite of Q5 and Q95 between the positive and negative PDO phases are about 2–3 days.

The estimation of F5 and F95 changes during the PDO phases for all Black Sea stations was made for the common time period 1950–2014. The calculation procedure of extreme temperature frequency during different phases of climate processes is described in details above. It is obtained that the positive PDO phase, relative to its negative phase, in winter is accompanied by a significant decrease F5 by more than 50% the primarily in the whole Black sea region. The F95 is also significantly decreased, but only in summer. The values of their difference composite are about 80%.
Figure 1. The time-series of the annual PDO index (a), the 5th percentile of intra-seasonal temperature anomalies in winter (b), the number of days with temperature below the 5th percentile (c) in winter and with temperature above the 95th percentile (d) in summer at the Simferopol station for 1900–2005. The horizontal lines and numbers on (b), (c) and (d) represent the average value of number of days with extreme temperature during the climate epochs, determined by changes of the sign of the PDO index. Vertical lines show significant shifts in the average values of PDO index in 1910/1911, 1946/1947 and 1976/1977.

Figure 2. The difference of frequency (%) of extreme low temperatures in winter (a) and extreme high temperatures in summer (b) during the positive and negative AMO phases. Significant at 95% level values are indicated by triangles, insignificant values are marked by dots.
3.2. **AMO**

At first, we analysed the longest time series of the extreme air temperature characteristics in winter during the AMO phases for some stations. It is obtained that the winter P5 of air temperature anomalies during the positive AMO phase is about 1–2 °C less, than during the opposite phase. It means that air temperature became lower. However, the Q5 during analysed conditions is more than 1–2 days. Significant differences of extreme air temperature characteristics between the AMO phases in summer are not found.

The common composite analysis of extreme air temperature frequencies at the analysed region during AMO phases were done for period 1950–2014. The F5 during the positive phase of studied climate process in winter is increased more than 2 times in comparison with the negative phase (figure 2a). The F95 in summer is increased. But the differences are primarily statistically insignificant (figure 2b) excepted on is some parts of the Black sea region. It is north-western coastline of the studied region (Odessa), central and eastern part of the Crimean peninsula (Simferopol and Feodosiya, respectively) and the Black Sea coast of Russian Federation (Anapa and Tuapse).

4. **Conclusions**

- The extreme changes of air temperature characteristics in the Black Sea region in winter and summer are associated with PDO and AMO.
- The most intensive PDO and AMO manifestations in the extreme air temperature characteristics changes are observed in winter, while their manifestations in summer are less pronounced.
- The extreme winter air temperature anomalies during the positive PDO phase and negative AMO phase are increased by about 2 °C.
- The frequency of extreme low air temperature in winter during the positive PDO phase and negative AMO phase is more than twice decreased.

Thus, the obtained estimations of extreme air temperature changes can contribute to improving the reliability and durability of buildings and structures, to reducing energy demands for their heating and (or) cooling.

5. **References**

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