Anomalies of Temperature and Annual Runoff of the Danube River in the Wide Range of Solar Variability Scales

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Abstract—Analyzed is the variability of precipitation in the area of the southern coast of the Crimea and the Danube River catchment as well as of the Danube River runoff. It is demonstrated that minimum precipitation and minimum runoff of the Danube River were observed in the years with the minimum of the quasicentennial cycle of solar activity (1879–1933), when the index of North Atlantic Oscillation (NAO) was maximum. The precipitation and the Danube River runoff were maximum in the years with the quasicentennial maximum of solar activity (1934–1996), when the NAO index was minimum. It is obtained that in the regions under consideration precipitation and the Danube River runoff are minimum in the years of the even cycle of solar activity and maximum in the years of the odd cycle. Discussed is the considerable difference in the interannual distribution of total precipitation in the catchment of the Danube River and its runoff in the years of even and odd cycles of solar activity.

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INTRODUCTION

Significant variations of total annual precipitation and annual river runoff observed in recent years in the Black Sea area [4, 12, 13] affect economic activity and cause abnormal floods in a number of cases [8]. All factors affecting atmospheric circulation which forms the moistening regime in the river catchments should be maximally taken into account for the prognostic estimation of the probability of such extreme runoff. It is considered nowadays that the climate variability of recent 50 years is caused by human activity in 90% of cases [9]. However, in the IPCC Fourth Assessment Report [9], the attention is paid to the significant natural variability of climate at the regional scale. One of the factors defining the climate variability in the concrete region is solar activity varying within wide limits [2, 3] and influencing the air pressure field [10, 14], i.e., atmospheric circulation. In the papers published in recent years the authors demonstrated that hydro-meteorological fields in the atmospheric surface layer of the Atlantic European sector are sensitive to the variations of solar activity at the scales from quasicentennial to quasivicennial [6, 7]. Taking into account the results presented in these papers, let us try to assess the variability of the Danube River runoff associated with solar activity at different time scales. The choice of the Danube River and its catchment is caused by the availability of the rather long series of observations of its runoff that enables us to obtain the estimates in the wide range of time scales. Since the Danube catchment is situated in the same climate zone as the catchments of the rivers in the northern part of the Black Sea region, it can be expected that the estimates of variations of its runoff for a long time period will be suitable for assessing the runoff of rivers in the south of Ukraine.

It was interesting to investigate how the variations of the annual runoff of the Danube River depend on the moistening in its catchment at the different regimes of atmospheric circulation in the Atlantic European sector formed by the solar activity in the wide range of time scales, from quasicentennial to interannual.

DATA AND PROCESSING METHODS

To assess the variability of moistening in Southern Europe and the Danube River runoff, the datasets were used of total monthly precipitation in Yalta and the monthly runoff of the Danube River for 1881–1996 that are available in the archives of the Marine Hydrophysical Institute of the National Academy of Sciences of Ukraine. The total monthly precipitation in the Danube catchment were taken from the
CRU TS 2.0 climatic dataset [20] for the territory limited with the coordinates of 42°–47° N, 15°–26° E. In this dataset, precipitation data are presented with the resolution of 0.5° × 0.5°. To assess the variability of atmospheric circulation in the Atlantic European sector, the NAO index was used [18]. Time scales of fluctuations of solar activity were analyzed using the array of Wolf numbers presented in [19]. It was taken into account that the datasets of precipitation and the Danube River runoff used by the authors of this paper were referred to the time period corresponding to the current quasicentennial cycle of solar activity. Therefore, the data processing was based on the technique presented in [7]. Initial series were smoothed by the averaging for 11 years (the mean duration of the 11-year cycle of solar activity) and the variability of precipitation and the Danube River runoff during the even and odd cycles of solar activity was estimated using data samples for the years referred to these cycles. The interannual variability of analyzed characteristics in the years of the even and odd cycles of solar activity was studied using the so-called method of superimposed epochs [3]. The anomalies of total annual precipitation and annual runoff of the Danube River were computed in the following way: \( P' = P_i - P_m, Q' = Q_i - Q_m \), where \( P_i \) and \( Q_i \) are the values of the amount of precipitation and runoff for the selected years referred to the even or odd cycle, \( P_m \) and \( Q_m \) are the mean values of the amount of precipitation and runoff for the whole time series. The mean values of \( P' \) and \( Q' \) for the years of the even and odd cycles of solar activity were used for the subsequent analysis. The statistical reliability of obtained results was assessed using the standard procedures [1, 21].

**OBTAINED RESULTS AND THEIR ANALYSIS**

In [7], the variability was analyzed of atmospheric circulation in the Atlantic European sector (NAO index) in the years of the minimum and maximum of the current quasicentennial cycle of solar activity. These years were notable for the values of Wolf numbers \( W \) [2]. The years of the minimum corresponded to the time period from 1879 to 1933 (period 1) and the years of maximum were represented by the time period from 1934 to now (period 2). To estimate the total precipitation in Southern Europe and the Danube River runoff, let us use such division of processes into two periods. Since the available data on the Danube River runoff were limited by 1996, the period 2 is presented by the time period from 1934 to 1996 in the subsequent analysis. Precipitation in Southern Europe was presented by total monthly precipitation in Yalta, i.e., by the longest series of precipitation observations in this region. The variability of total annual precipitation in Yalta and the annual runoff of the Danube River depending on the atmospheric circulation (the NAO index) in the years of quasicentennial minimum and maximum of solar activity is the following:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period 1</th>
<th>Period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W )</td>
<td>39 (±7)</td>
<td>73 (±12)</td>
</tr>
<tr>
<td>NAO</td>
<td>0.26 (±0.44)</td>
<td>0.15 (±0.48)</td>
</tr>
<tr>
<td>( P' ), mm</td>
<td>-31 (±38)</td>
<td>28 (±40)</td>
</tr>
<tr>
<td>( Q' ), m³/s</td>
<td>-163 (±274)</td>
<td>138 (±291)</td>
</tr>
</tbody>
</table>

(In brackets, the confidence intervals are given that correspond to the confidence probability of 95%.)

It is clear that the NAO index was maximum in the years of the minimum of the quasicentennial cycle of solar activity (period 1) and it was minimum in the years of the maximum of this cycle (period 2). At maximum values of NAO index, cyclonic trajectories are mainly in the northern part of the Atlantic European sector, and at minimum values, in Central and Southern Europe [21]. According to these features of atmospheric circulation in the years with the maximum values of NAO index, the abnormally high amount of precipitation and the Danube River runoff is provided by the influence of Atlantic and Mediterranean cyclones.

The strict estimation of the significance of the above results, for example, the use of the hypothesis on the equality of two centers of distribution [17] gives the reason to suppose that only the differences in the values of \( W \) and precipitation anomalies in Yalta between periods 1 and 2 are significant at the 95% level of confidence probability. The differences in the NAO index and the Danube River runoff are insignificant. The existence can be supposed only of the trend towards the exceeding of the NAO index in the years of quasicentennial minimum of \( W \) over its values in the years of quasicentennial maximum of solar activity. Hence, the Danube River runoff has the trend towards maximum values in the years of period 2 and towards minimum values in the years of period 1.

The used data on precipitation in Yalta characterize the moistening regime in Southern Europe but this station is situated at the significant distance from the Danube catchment. Therefore, the assessment of the variability of the anomalies of total annual precipitation was based on the data of Kherson and Odessa station located closer to the Danube River. Available precipitation observation series at these stations start since 1900. The values of the anomalies of total annual precipitation \( P'' \) (mm) in Yalta, Kherson, and Odessa are given for the comparison: