

Seasonal and Nonstationary Nature of European Climate Variability in the Twentieth Century

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Air temperature and precipitation are key climatic parameters, anomalies of which have a severe impact on the life and activity of mankind. As an example of such anomalies, we refer to the summer of 2002 when prolonged draughts in central European Russia provoked spacious and intense forest fires. A year later, almost all western and central Europe suffered lack of precipitation and extreme high air temperatures, resulting in catastrophic forest fires and an increase in the death rate among inhabitants [1]. Successful prediction of such climatic anomalies will allow us to reduce the damage inflicted by them. In recent years, increasingly greater attention has been given to study of seasonality in climatic variations of different scales [2–5] and long-period variability in characteristics of seasonal cycle [6–9]. Multidirectional variations in different seasons may indicate variations in the continental character of climate, which may appear to be no less an important climatic signal than variations in annual mean values of various parameters.

Based on century-long observation data, we studied the leading variation modes of the European climate in the twentieth century with special emphasis on their seasonal and nonstationary nature. We used data on the air temperature and precipitation from the CRU05 database [10]. The database was created in the Climatic Research Unit, University of East Anglia. It comprises monthly mean data for land with a latitude and longitude resolution of 0.5° for the period of 1901–2000. Detailed information on the methods of the database construction is presented in [10]. Data on the North Atlantic Oscillation (NAO) index presented in [11] for the period from 1900 to the present day were also used in this work.

To study the spatiotemporal structure of covariability of air temperature and precipitation, which is not related to trend variations, we applied the so-called linear singular value decomposition (SVD) analysis, which represents a modification of principal components analysis and allows us to distinguish and study basic modes of covariability of two climatic parameters [12, 13]. We shall restrict our considerations only to first SVD-modes, which describe the most part (from 45 to 73%) of covariability of air temperature and precipitation in Europe in each season. We also use standard correlation analysis and analysis of running correlations for studying relationships with the main climatic signal in the Atlantic–European sector (NAO).

The first SVD-mode for winter is characterized by coherent variations in the air temperature over all of Europe with maximal magnitudes in the Baltic Sea region and minimal magnitudes over southern Europe (Fig. 1, left panel). Corresponding variations in the precipitation field are characterized by a meridional dipole with opposite variations of precipitation over northern and southern Europe (Fig. 1, right panel). Both patterns are typical for the positive NAO phase [11]. The association of the first SVD-mode of winter air temperature and precipitation with NAO is confirmed by a high correlation with its index (Table 1). In spring, the spatial patterns of the first SVD-mode of the air temperature (Fig. 1, left panel) and precipitation (Fig. 1, right panel) are similar to patterns obtained for winter. However, the area of maximal magnitudes of air temperature variability shifts to the central part of European Russia, and maximal magnitudes are observed over Western Europe. Spatial patterns of the first SVD-mode for the summer air temperature and precipitation differ basically from the above-discussed patterns for winter and spring. Variations in the temperature field related to this mode are characterized by a zonal orientation of the dipole with opposite temperature variations over Western and Eastern Europe/European Russia (Fig. 1, left

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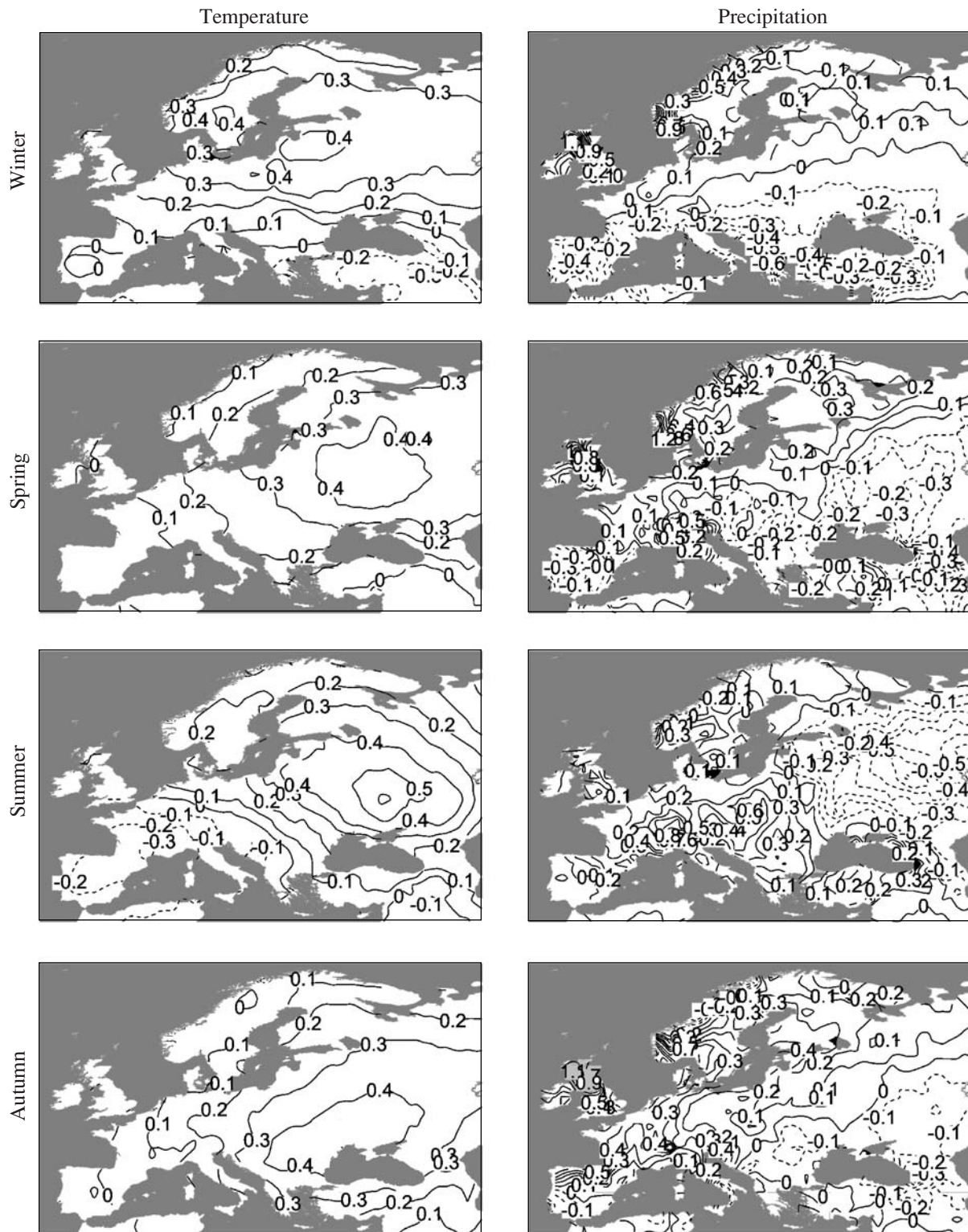


Fig. 1. Spatial patterns of the first SVD-mode for the air temperature and precipitation calculated for winter, spring, summer, and autumn. Values are nondimensional. Positive (negative) values are shown in solid (dashed) line.

panel). A similar dipole (but with opposite signs of anomalies) characterizes the variability of summer precipitation as well (Fig. 1, right panel). This mode

reflects local interrelations between the air temperature and precipitation when, for instance, extremely high temperatures (associated with anticyclone regimes of

Table 1. Correlation coefficients (R) between the principal components of the precipitation and air temperature of the first SDV-mode and the NAO index

Season	R	
	Precipitation	Temperature
Winter	0.90	0.76
Spring	0.55	0.50
Summer	0.12	0.27
Autumn	0.46	0.50

Table 2. Contributions (%) of the first SDV-mode to the common joint variability of the temperature and precipitation and correlation coefficients (R) between the corresponding principal components

Season	SVD-1, %	R
Winter	73.1	0.78
Spring	61.3	0.74
Summer	45.7	0.76
Autumn	59.0	0.71

the atmospheric circulation in summer) are accompanied by a deficiency of precipitation. The correlation analysis showed that the leading SVD-mode is not associated with NAO in summer (Table 1). In autumn, spatial patterns of the first SVD-mode of the air temperature (Fig. 1, left panel) and precipitation (Fig. 1, right panel) become similar to the winter and spring patterns. The maximal variability of the temperature is observed north of the Black Sea; the minimal variability, over the Iberian Peninsula and Scandinavia (Fig. 1, left panel). As in winter and spring, the spatial pattern of the first SVD-mode for autumn precipitation represents the meridional dipole (Fig. 1, right panel).

The contribution of the first SVD-mode to the general covariability of the temperature and precipitation over Europe considerably varies from season to season (Table 2). The maximal contribution is observed in winter (73.1%); the minimal contribution, in summer (45.7%). Along with differences in the patterns mentioned above, this is one further manifestation of the seasonal nature in principal components of the European climate. Correlations between the principal components of the first SVD-mode for the temperature and precipitation are high and vary from 0.71 in autumn to 0.78 in winter, not exhibiting substantial variation between seasons (Table 2).

Since NAO represents the main climatic signal in the Atlantic–European sector, which substantially governs principal components of the temperature and pre-

cipitation in the region [4, 11], we studied the stability of links of these variations with NAO based on the analysis of running correlations between the principal components of the above-considered first SVD-mode and NAO index. We used a 21-yr running window. The statistical significance of the correlations obtained was assessed by the Student criterion [14]. In winter, correlations of the principal components of the temperature and precipitation with the NAO index are high and statistically significant for the entire twentieth century (Fig. 2). They demonstrate a positive trend, which has grown considerably since the late 1960s. This growth is related both to the positive NAO trend [11] and to intensification of global warming during the last few decades [15]. In general, correlations for precipitation are considerably higher than those for the air temperature. Spring correlations demonstrate clear variability between decades with high values in the first half of the twentieth century and low values in the later period (Fig. 2). In summer, correlations of the principal components of the temperature and precipitation with the NAO index are statistically insignificant throughout the twentieth century (Fig. 2). Correlations for autumn exhibit clear variability between decades (Fig. 2). High correlations are observed in the first half of the twentieth century for both precipitation and air temperature. Correlations with the NAO index for precipitation are insignificant in the second half of the twentieth century. Correlations for the temperature are statistically insignificant in the 1950s, significant from the mid-1960s to the mid-1970s, and again insignificant later. It should be noted that correlations of the temperature with the NAO index are substantially higher than those for precipitation in the second half of the twentieth century.

The analysis of leading modes of covariability of the temperature and precipitation over Europe revealed their seasonal nature. Seasonality shows up both in the structural difference of leading modes and in their relative contribution to the total covariability of the temperature and precipitation. The weakening of the NAO role and the consequent heat and moisture advection to the European region at the transition from a cold season to a warm season is a physical cause of the revealed differences. In summer, the role of local processes increases. The analysis of links with the NAO revealed their essential nonstationary nature. The seasonal and nonstationary nature of climatic variations is responsible for annual and more prolonged variations in characteristics of the seasonal trend [6, 7]. Climatic periods characterized by an increase or decrease in the NAO influence on the temperature and precipitation variability over Europe have been distinguished. Decrease in the NAO influence may be accompanied by increase in the role of other modes of atmospheric circulation. The results of this study indicate that mechanisms of the formation of the European climate and its variations have changed substantially with time. Hence, when modeling and predicting the regional climate, even successful

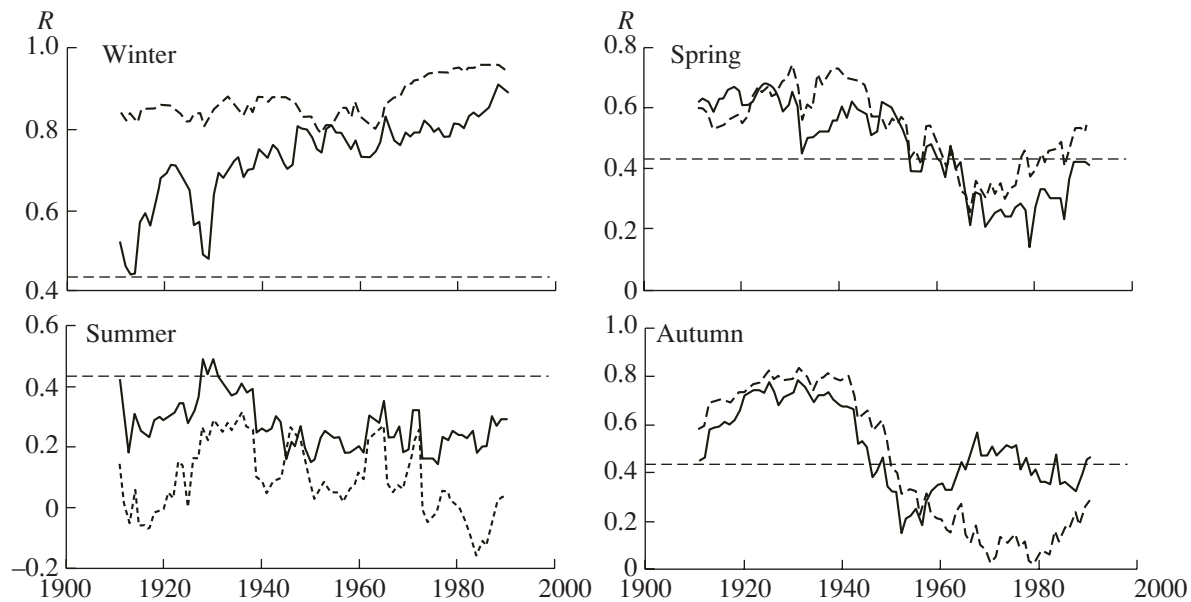


Fig. 2. Running coefficients of correlation between the principal components of the first SVD-mode and the NAO index. The solid line shows correlations for the air temperature; the dashed line, for precipitation. The horizontal dashed line designates a significance level of 95%.

prognostic schemes should periodically be revised and refined.

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