Interannual Variability of Soil Moisture in the European Part of Russia in Summer

I. I. Zveryaev, A. V. Arkhipkin

Abstract—Interannual and interdecadal variability of soil moisture in the European part of Russia in summer months is investigated using the data for 1948–2012. It is found that the two first empirical orthogonal functions (EOFs) describe about 50% of total variability of soil moisture. The spatial pattern of the first EOF is indicative of coherent changes in soil moisture in the whole European part of Russia. The second EOF is represented by the meridional dipole with the opposite signs of soil moisture variations in the northern and southern parts of the region. It is revealed that the spatiotemporal pattern of the principal EOFs of soil moisture variability in the European part of Russia almost does not vary during summer that is indicative of the uniform (for each EOF) mechanism of the formation of interannual variability of soil moisture.

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INTRODUCTION

Soil moisture is a major climatic parameter whose temporal variability in a concrete region is fundamental for the determination of climate in this region [13]. It is stated in [9] that soil moisture is a key parameter in hydrological processes which also affects the growth of plants and carbon fluxes. Moreover, soil moisture is critically important for predicting weather and climate as it controls the local sources of atmospheric moisture and the division of surface energy fluxes into sensible and latent heat fluxes [5].

It should be noted that soil moisture is characterized by significant variability in space and in time. The range of scales of this variability is rather wide; however, the present paper deals with the analysis of large-scale (interannual) variability of soil moisture in the European part of Russia (hereinafter, EPR) in summer. As noted in [1], there are problems which require the generalization of soil moisture rather than its detailing. Such problems include the long-range forecasting where soil moisture can be used both as a predictor and as a predictand. It is obvious that only general features of soil moisture pattern on the vast territory (such as EPR) can be predicted with the large lead time. This is also true in case of using soil moisture as a predictor.

Based on the modern dataset [10, 11], the present study considers the characteristics of large-scale climatic variability of soil moisture in the European part of Russia (45°–60° N, 30°–50° E) in summer. The variability scales under consideration mainly include interdecadal and interannual variability. The summer is chosen for the analysis because local processes are important for the variability of weather and climate during the warm season and relevant for agriculture. Also, the estimation of this parameter during the cold season is highly uncertain (due to the soil freezing and snow cover). In recent years, the interest to the analysis of soil moisture variability has increased in view of the general trend towards frequent droughts. In particular, several papers investigate soil moisture anomalies in EPR in the context of the drought in 2010 which was associated with the strongest (over the period of instrumental observations) heat wave [2–4]. However, it should be noted that no comprehensive analysis of large-scale variability of soil moisture in EPR has been carried out since the moment of publication of paper [1] (more than 30 years ago). In view of this, the study based on modern data and covering the longer period of observations characterized by the intensification of global warming is topical.

DATA AND METHODS

The data on soil moisture from the dataset prepared in the NOAA Climate Prediction Center (USA) were used for the analysis. The set includes global data on soil moisture with the resolution of 0.5° along the latitude and longitude for the period from 1948 to present [11, 15]. These data are characterized by the relatively high spatial resolution and cover the considerable time period. It should be noted that these are the outputs of the single-layer hydrological model [10, 11]. This model assimilates the data of observations of precipitation and air temperature and simulates soil moisture, evaporation, and river runoff based on them. The more detailed information about the model and the dataset construction is presented in [10, 11, 15]. As the model data are used, the comparative analysis with satellite data was provided and revealed a good agreement between the large-scale anomalies of soil moisture from the data of these two datasets. In particular, Figure 1 presents the anomalies of soil moisture content (computed relative to the mean value for 1987–2012, i.e., for the period provided with satellite data) for two years characterized by the positive and negative anomalies of soil moisture in EPR. It should be noted that the detailed coincidence of the structure and amplitudes of the anomalies was not expected because the data indicate soil moisture for different layers (the upper 160 cm for the model data and 2 cm for the satellite data). Nevertheless, it is clear that the good agreement between the model and satellite data is generally observed in EPR.

The authors of the present paper used decomposition to empirical orthogonal functions (EOFs) for studying the spatiotemporal pattern of long-period variations in soil moisture in EPR which are not related to trends [16, 17]. The spatial pattern and the respective principal components of the first two EOFs are discussed in detail. Although the possible reasons for the formation of soil moisture variability (for example, the effects of regional teleconnections) are also briefly considered in the paper, the more thorough analysis of formation mechanisms of soil moisture variability in EPR is the further research subject.

RESULTS

The spatial patterns of the first EOF of soil moisture for each summer month are presented in Figs. 2a, 2c, and 2e. It is clear that the soil moisture variations related to the first EOF are coherent in EPR in all months, i.e., the presented values are of the same sign. However, there are some differences between the
months. The patterns of the first EOF in June (Fig. 2a) and July (Fig. 2c) are rather similar, whereas the appreciable broadening of the zone of the maximum variability and its spread to the northwestern part of the region under study are detected in August (Fig. 2e).

The contribution (%) of the first and second EOFs to the total variability of soil moisture in the European part of Russia in summer months is:

<table>
<thead>
<tr>
<th>Month</th>
<th>First EOF</th>
<th>Second EOF</th>
</tr>
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<tbody>
<tr>
<td>June</td>
<td>36.3</td>
<td>13.5</td>
</tr>
<tr>
<td>July</td>
<td>33.7</td>
<td>15.3</td>
</tr>
<tr>
<td>August</td>
<td>34.1</td>
<td>17.7</td>
</tr>
</tbody>
</table>

Obviously, the first EOF makes significant contribution (from 33.7% in July to 36.3% in June) to the total variability of soil moisture in EPR. The time series of the principal components of the first EOF of soil
moisture in EPR exhibit the similar interannual variability in June, July, and August (Figs. 3a, 3c, and 3e). This is corroborated by high correlation between the considered time series. For example, the correlation between the principal components of the first EOF is 0.90 in August and July and 0.68 in August and June. The presented correlations (see the table) are statistically significant at the level of 99% according to the $t$-test [8] that corroborates the above similarity between the principal components of the first EOF for different months. The plots of moving averages (the window width is 11 years, the curves in Fig. 3) characterize the interdecadal variability of soil moisture. In particular, long periods of high soil moisture (for example, in the late 1970s–early 1980s and in the 2000s) and the periods of relatively dry conditions (for example, 1983 to 1999) are observed. It should be noted that the identified dry period in the second half of the 1960s–early 1970s and the preceding period of high soil moisture are generally consistent with the results obtained in [1] (see Fig. 14) from other data. The registered interdecadal anomalies are more strongly pronounced in June (Fig. 3a). It should also be noted that the principal components of the first EOF of soil moisture in July and August (Figs. 3c and 3e) indicate well the drought in EPR associated with the extreme heat wave in 2010 [7, 20]. It is interesting that the negative anomalies of soil moisture in 1972 (the severe drought was also observed) are slightly larger than in 2010 (Figs. 3c and 3e). This may be caused both by a certain model imperfection and by physical reasons. For example, the delayed effect of moisture accumulated in the previous months could slightly weaken soil moisture anomalies in the summer of 2010. In general, the obtained results suggest that, despite some above local differences between different months, the first EOF of soil moisture in EPR characterizing its relatively long-period interannual and interdecadal variations is evidently of the common genesis and vary little from month to month. This indicates the conservativeness of the parameter under study.

Figures 2b, 2d, and 2f present the spatial patterns of the second EOF of soil moisture in EPR. Unlike the patterns of the first EOF, the patterns of the second EOF in all summer months are indicative of soil moisture variations of different directions (i.e., of different signs) in the northern and southern parts of EPR. Thus, the variability of soil moisture related to the second mode of EOF is characterized by the meridional dipole. The variations of the pattern of this mode from month to month are not significant and are mainly
manifested in the variability increase in the southern part of the region and in the variability with the opposite sign in its northwestern part in August (Fig. 2f). This EOF describes 13.5% (June) to 17.7% (August) of total variability of soil moisture in EPR. As for the first EOF, the time series of the principal components of the second EOF of soil moisture in EPR demonstrate the similar interannual variability in June, July, and August (Figs. 3b, 3d, and 3f) which is corroborated by the high correlation between the time series under consideration (see the table). It should be noted that the time series of moving averages indicate the longer (as compared to the first EOF) interdecadal variations in soil moisture in EPR (Figs. 3b, 3d, and 3f). Nevertheless, it should be remembered that the second EOF describes essentially smaller portion of the total variability of soil moisture.

Since the essential contribution to the soil moisture variability in EPR can be made by changes in atmospheric moisture advection to the region (with the subsequent precipitation), the correlation analysis was applied to study briefly possible relationships between the principal EOFs of soil moisture variability and the major teleconnection patterns [6] such as the North Atlantic Oscillation [12], Scandinavian teleconnection pattern, East Atlantic teleconnection pattern, etc. In general, the analysis revealed relatively poor correlations with regional teleconnections. In particular, the highest correlation coefficients were detected in August between the principal components of the first EOF of soil moisture and the index of the Scandinavia teleconnection pattern (0.27) and in June between the principal components of the second EOF of soil moisture and the index of the East Atlantic/Western Russia teleconnection pattern (0.28). Although both correlation coefficients are statistically significant at the level of 95%, it is obvious that they are indicative of the poor links with the large-scale atmospheric dynamics in the region. The detected weak correlation between the soil moisture variability and regional teleconnections may partly be explained by the fact that two major climatic parameters forming the soil moisture variability (precipitation and air temperature) exhibit the interannual variability of different types in summer which is controlled by different mechanisms [18, 19].

CONCLUSIONS

This paper studied the principal modes of soil moisture variability in EPR in summer for the period of 1948–2012 using the decomposition to empirical orthogonal functions. It was found that the first EOF describes the coherent interannual (and interdecadal) variability of soil moisture on the whole territory of EPR. Despite some differences in spatial patterns, this EOF is evidently a manifestation of common (for all summer months) signal of the same origin. This is also evidenced by high correlations between the respective principal components. The second EOF of soil moisture is characterized by the spatial pattern in the form of a meridional dipole with the opposite variations in soil moisture in the northern and southern parts of EPR and demonstrates the significant persistence from month to month. The contribution of this EOF to the total variability of soil moisture is about half of the first EOF contribution. It was revealed that principal components of the first and second EOF of soil moisture in EPR exhibit very similar behavior in all summer months and rather highly correlate with each other. This indicates the relative conservativeness of this climatic parameter.

Summarizing the results of the present study, we note that the spatiotemporal patterns of interannual climatic variability of soil moisture in EPR in summer in the second half of the 20th century—the beginning of the 21st century were analyzed using the modern dataset. It was found that the first two EOFs describe about a half of the total variability of soil moisture in EPR and demonstrate high persistence from month to month both in terms of spatial patterns and in terms of their principal components that suggests the single mechanism of their formation in different months. The soil moisture variability in EPR is caused by many factors (precipitation, air temperature, etc.) that complicates the identification of its formation mechanisms. The preliminary analysis of synchronous correlation between the EOFs of soil moisture and the major regional teleconnections revealed relatively poor correlations with the prevailing atmospheric circulation patterns. Perhaps, the analysis that includes the lead-lag soil moisture correlations both with regional climate signals and more distant teleconnections, will be more promising. The search of formation mechanisms of the revealed soil moisture variability in EPR has another (and quite logical) potential direction. It includes experiments with modern climate models with high spatiotemporal resolution using constantly improving satellite datasets.
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REFERENCES