Changes in climatic extremes of the south of Russia associated with El Niño events

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Abstract. Spatial and temporal distributions of extreme temperatures and precipitation over the south of Russia in 1950–2018 are discussed, and their features are associated with El Niño events. Analysis of the temperature extremes shows some warming in the region during this study period. Extreme precipitation indices indicate upward tendencies on average in a region with strong spatial heterogeneity. The manifestations of some El Niño types in extreme temperatures are most noticeable in the winter-spring period, with warming during the eastern and cooling during the central type. The El Niño manifestations in extreme precipitation are less clear. Only the autumn season should be highlighted, when extreme precipitation is higher in the North Caucasus during the central El Niño type.

1. Introduction
The behavior of temperature and precipitation extremes has significantly changed during the past centuries according to the IPCC re [1]. Natural variability in the ocean and atmosphere system affects climatic extremes [2]. The strongest interannual scale signal of the coupled atmosphere-ocean system is El Niño-Southern Oscillation (ENSO) [3, 4]. The warm phase of ENSO is El Niño, a periodic (once in 2–7 years) abnormal warming of surface waters in the equatorial zone of the Pacific Ocean [5]. During the ENSO events large-scale restructuring of the atmosphere and ocean interaction occurs throughout the tropical Pacific. El Niño has a significant influence on weather and climate of extratropical regions of the Earth (e.g., [6, 7] and others). The mechanism of El Niño influence on the hydrometeorological conditions of European region is still being specified. The complexity is in the variability of El Niño events (their intensity, duration, location, maximum sea surface temperature anomalies, and others). An analysis of the relationship between hydrometeorological extremes and El Niño events was carried out on different scales [8–11]. Manifestations of El Niño events in different regions of the world are heterogeneous. Thus, the aim of this paper is to study the behavior of extreme temperature and precipitation in the south of Russia in 1950–2018 and manifestations of different El Niño types in extremes.

2. Data and methods
Daily data on the minimum and maximum air temperatures and precipitation for 1950–2018 from 21 meteorological stations over the territory of the south of Russia were used (Figure 1). The data were taken from the archive "All-Russian Research Institute of Hydrometeorological Information – World Data Centre" (RIHMI-WDC) (http://aisori-m.meteo.ru) and ECA&D (https://climexp.knmi.nl). The indices of extreme temperatures and precipitation recommended by the WMO were used to detect extreme events [12, 13]. The ETCCDI climate indices used in the paper are as follows: (1) TN10p (the
so-called cool nights), the percentage of days when TN < 10th percentile (% of days); (2) TX90p (the so-called warm days), the percentage of days when TX > 90th percentile (% of days); (3) RX1day, maximum 1-day precipitation total (mm), and (4) RX5day, maximum 5-day precipitation total (mm). The 10th and 90th percentiles were calculated for the basic period 1961–1990 [13]. The data quality control and calculation of the indices were performed using RCLimDex software [14]. The manifestation of different types of El Nino was estimated by composite analysis. Mathematical statistic methods and regression analysis (for linear trends fitting) were applied. The statistical significance of the linear trends was evaluated by the Students t-test (p<0.05).

Figure 1. Study region and location of stations.

3. Results

3.1 Spatial and temporal distribution of extreme indices

The TN10p index (in %) or the so-called “cool nights” determines the proportion of days with minimum temperatures below the 10th percentile of the daily minimum temperature distribution in the basic period 1961–1990 [15]. This index allows estimating the number of extremely low temperatures related to intense frosts. The analysis of the number of cool nights in 1950–2018 showed that the mean annual TN10p values range from 9% on the Black Sea coast of the Caucasus to 13% in the eastern part of the analysed region. The TX90p index determines the proportion of days with maximum temperatures above the 90th percentile to the distribution of the daily maximum temperature in the basic period 1961–1990 [15]. This index estimates the number of extremely high temperatures and is also called “warm days”. An analysis of the number of warm days (TX90p) for 1950–2018 showed that the mean annual TX90p values varied from 12% in the central part of the studied region to 16.5% in the southeast of the region.

The selected extreme precipitation indices characterize the magnitude of intense rainfall events [16]. The highest values of precipitation extreme indices are located on the Black Sea coast of the Caucasus. The one-day precipitation maximum (RX1day) varied from 25.7 mm per day in the coastal zone of the Caspian Sea to 87 mm per day on the Black Sea coast. The distribution of maximum 5-day precipitation values (RX5day) repeats the RX1day index distribution. The index values changed from 35 mm per day to 166 mm per day.

In general, the region is characterized by a downward tendency of extremely low temperatures (cool nights) and an upward tendency for high temperatures (warm days) (Figure 2, a and b). The rate of change of the TN10p index is −1.1% per 10 years and that of the TX90p is +1.5% per 10 years. Both precipitation extreme indices indicated positive regional average trends for 1950–2018 with trend values from +0.9 mm for the RX1day index to +1.3 mm per 10 years for the RX5day index,
respectively (Figure 2, c and d). All trends are statistically significant (p<0.05). The spatial distribution changes in the extreme temperatures have a uniform distribution. The annual average of the TN10p index shows downward trends for all stations (except Makhachkala). The trends varied from –0.5 % per 10 years to –2 % per 10 years in the central part of the studied region. The TX90p index is characterized by the opposite picture. All trends are positive and statistically significant (p<0.05). The maximum positive linear trend value is typical for the northwest of the region, and reached +4% per 10 years (Derbent station). Thus, the temperature indices show the tendency to warming over the south of Russia in 1950–2018. The trends of the extreme precipitation indices are predominantly positive, but most of them are statistically non-significant during 1950-2018. The growth of the RX1day index reaches +4.8 mm per 10 years, and that of the RX5day index +6 mm per 10 years on the Black Sea coast of the Caucasus (Tuapse station). The single negative trends are small and non-significant.

Figure 2. Annual regional average time series of the climate extreme indices (solid line) and trends (dotted line) for 1950–2018.

3.2 Manifestations of different El Niño types
An objective space-time classification of El Niño events was used to assess the response in extreme temperatures and precipitation [17]. According to this classification, two types of events are distinguished: spring eastern and autumn central types. The eastern type of El Niño by the selected classification was in 1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1997, 2006, and 2015. The central type of El Niño happened in 1968, 1977, 1986, 1991, 1994, 2002, and 2009. To compare the regional manifestations of El Niño types, the difference (%) in the indices of extreme temperatures and precipitation for the seasons was calculated between the average values in "+1" year after the onset of different types of El Niño. The clearest manifestations of El Niño events in extreme temperature indices were found for the winter and spring seasons. The TN10p index values are higher during the central El Niño type throughout the region. The difference reaches 50% in the Crimea and over the northern part of the studied region in winter (Figure 3a). In spring the difference between the two types of El Niño in minimum temperatures is higher for the region as a whole compared to winter, except for the northern coast of the Caspian Sea (Figure 3b). The distribution of the difference in the values of the TX90p index between the two types of El Niño in the winter-spring season is opposite to the TN10p index. The values of “warm days” are higher during the eastern type (Figure 3c and d). The summer and autumn seasons are characterized by a strong heterogeneity in the distribution of the difference in the indices between the two types of El Niño. It can be concluded that in the years of the eastern El Niño
type in the winter-spring period extremely high temperatures are observed more often, and in the years of the central El Niño type, on the contrary, there is an increase in the frequency of extremely cold temperatures. These conclusions are consistent with the results of [18], in which warming was during the eastern type and a significant cooling in the winter season during the central type of El Niño in Europe.

The spatial distribution of the percentage differences between the two El Niño types for the extreme precipitation indices is not homogeneous and similar (it is shown only for the index RX5day in Figure 4). The winter season is characterized by a mixed structure. In spring and summer, on the territory of the Crimean Peninsula the values of the indices are higher during the eastern type of El Niño (up to 40% in the southeast of the peninsula). In summer, on the territory of the Stavropol Upland and in the eastern part of the region the index values are higher during the central El Niño type. In autumn, on the territory of the North Caucasus the values of the two indices are higher for the central El Niño type, with the maximum values on the Caspian Sea coast (the difference reaches 40%).
4. Conclusions
The above-analyzed distributions of temperature and precipitation extremes in the south of Russia and their long-term changes in 1950–2018 show significant changes in the behavior of the climatic extremes during this studied period. Significant linear trends of cool nights and warm days indicate a warming in the region. Extreme precipitation tends to increase, but the data are not everywhere statistically significant. The manifestations of some El Niño types in the extreme temperatures are most noticeable in the winter-spring period. Extremely low temperatures are often associated with the central type of El Niño, and extremely high ones – with the eastern type of El Niño. The spatial distribution of the differences in percentage between the two El Niño types for the extreme precipitation indices is not homogeneous. The autumn season should be highlighted, when extreme precipitation is higher in the North Caucasus during the central El Niño type. The above-obtained results demonstrate the importance of examining the different El Niño types in their regional manifestations.

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