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Recent changes in Georgia's temperature means and extremes: Annual and seasonal trends between 1961 and 2010

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ABSTRACT

Sixteen temperature minimum and maximum series are used to quantify annual and seasonal changes in temperature means and extremes over Georgia (Southern Caucasus) during the period 1961 and 2010. Along with trends in mean minimum and maximum temperature, eight indices are selected from the list of climate extreme indices as defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) of the Commission for Climatology of the World Meteorological Organization (WMO), for studying trends in temperature extremes. Between the analysis periods 1961–2010, 1971–2010 and 1981–2010 pronounced warming trends are determined for all Georgia-averaged trends in temperature means and extremes, while all magnitudes of trends increase towards the most recent period. During 1981 and 2010, significant warming trends for annual minimum and maximum temperature at a rate of 0.39 °C (0.47 °C) days/decade and particularly for the warm temperature extremes, summer days, warm days and nights and the warm spell duration index are evident, whereas warm extremes show larger trends than cold extremes. The most pronounced trends are determined for summer days 6.2 days/decade, while the warm spell duration index indicates an increase in the occurrence of warm spells by 5.4 days/decade during 1981 and 2010. In the comparison of seasonal changes in temperature means and extremes, the largest magnitudes of warming trends can be observed for temperature maximum in summer and temperature minimum in fall. Between 1981 and 2010, summer maximum temperature shows a significant warming at a rate of 0.84 °C/decade, increasing almost twice as fast as its annual trend (0.47 °C/decade). The Georgia-averaged trends for temperature minimum in fall increase by 0.59 °C/decade. Strongest significant trends in temperature extremes are identified during 1981 and 2010 for warm nights (4.6 days/decade) in summer and fall as well as for warm days (5.6 days/decade) in summer. Analyses demonstrate that there have been increasing warming trends since the 1960s, particularly for warm extremes during summer and fall season, accompanied by a constant warming of temperature means in Georgia.

1. Introduction

Weather and climate extremes have always played an important role in influencing natural systems and society. Given their importance and the prospect of changes in the future, it is very important to understand how and why weather and climate extremes have changed in the past. In its Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), the IPCC (2012) defines an extreme weather or climate event as "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable." For decades, climate change affected frequency, intensity, and duration of extreme events as stated in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007). Economic losses from weather- and climate-related disasters have also increased during the last 60 years and will have greater impacts on sectors with closer links to climate, such as water, agriculture and food security. The highest fatality rates and economic losses caused by hydro-meteorological induced disasters are registered in developing countries (IPCC, 2012). In Georgia, weather and climate extreme events are responsible for increasing economic losses, as the high mountainous ranges and adjacent lowlands of the Caucasus experience a highly sensitive reaction to recent climate change (MOE, 2009).

The globally averaged surface temperature data show a linear warming trend of 0.85 °C [0.65–1.06 °C] during the period 1880–2012.

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The total increase between the average of the 1850–1900 period and the 2003–2012 period accounts for 0.78 °C [0.72–0.85 °C], based on the single longest dataset available (IPCC, 2013). However, extreme climate events react more sensitively to climate change than mean climate values and therefore show larger variations and trends (Katz and Brown, 1992; Easterling et al., 1997, 2000; Kunkel et al., 1999; New et al., 2006; IPCC, 2007; Aguilar et al., 2009). Since the 1990s various regional studies have been carried out on temperature extreme indices, which proved that global warming is closely related to significant changes in temperature extremes (Manton et al., 2001; Peterson et al., 2002; Aguilar et al., 2005; Griffiths et al., 2005; Zhang et al., 2005; Haylock et al., 2006; Klein Tank et al., 2006, Moberg and Jones 2005). To date, studies on past observed changes in temperature extremes over Georgia have been carried out based on monthly data and associated weather and climate phenomena, such as drought, hurricanes and frost (Elizbarashvili et al., 2007, 2009a, 2011, and 2012). Elizbarashvili et al. (2013) found that the frequency of extremely hot months during the 20th century increased and extremely cold months decreased faster in the Eastern Georgia than in its Western counterpart. In addition, highest rates on warming trends of mean annual air temperature can be observed in the Caucasus Mountains, while the lowest are detected in the dry eastern plains. In Georgia temperature increased between 0.1–0.5 °C in eastern Georgia and decreased by 0.1–0.5 °C in western Georgia during 1906–1995 (World Bank, 2006). The region's glaciers have retreated during the last 100 years, and runoff from the glacier areas has been increasing, both seasonally and annually, in response to climatic warming (Elizbarashvili et al., 2009b).

Developing and transition countries such as Georgia are subject to numerous political, financial and institutional barriers in implementing a proper climate data monitoring system, including limitations on funding, technology and human resources (Page et al., 2004). The quality and quantity of accessible climate series still limit our understanding of the observed changes in climate extremes in Georgia. At the beginning of the 20th century, 40 meteorological stations were installed on the territory of Georgia to measure daily temperature minimum, maximum and precipitation. By the 1940s this number increased to 200. After the collapse of the Soviet Union in the early 1990s, the number of meteorological stations in Georgia shrank rapidly and the lack of station maintenance caused large measuring gaps. From 1991 to the present the number of meteorological stations has fallen to around 60 (World Bank, 2006). Currently only 13 synoptic weather stations are working on the territory of Georgia (Elizbarashvili et al., 2013).

The diverse physiographic conditions and large-scale circulation patterns over Georgia make it very difficult to detect regional changes with respect to climate extremes. Georgia is located in the Southern Caucasus between 41°–44°N and 40°–47°E and covers an area of 69,700 km². It borders Russia to the North, Azerbaijan to the Southeast and Armenia and Turkey to the South (Fig. 1). The topographic patterns throughout Georgia are very diverse. The relief declines from the Greater Caucasus Range in the North, with an elevation range of 1500–5000 m and the Lesser Caucasus with altitudes up to 3500 m in the South towards Transcaucasia, which stretches from the Black Sea coast to the Eastern Steppe. The Surami mountain chain with a maximum altitude of 1000 m connects the Lesser Caucasus with the Greater Caucasus and divides Transcaucasia into eastern and western lowlands (0–500 m) .

The Greater Caucasus represents an important climatic parting line towards Russia. It protects Transcaucasia from arctic high-pressure systems in winter originating from the Central Asian Region. The Southern Caucasus inhibits the summer heat from the Southeast. The Surami mountain chain avoids wet air masses

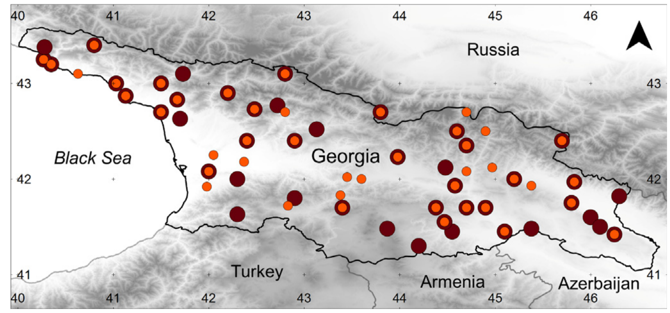

Fig. 1. Stations with daily minimum (orange dots) and maximum (red dots) temperature series for the period 1961–1990.

circulating from the Black Sea towards the Caspian Sea causing high temperatures and humid climate at the western coast, continental climate in inner Transcaucasia up to very dry climate with high temperatures in the eastern lowlands (Shahgedanova, 2002). In general, the west of Georgia is characterized by mild winters and hot summers with mean annual air temperatures of 13–15 °C and high annual precipitation values (1200–2400 mm). The climate in eastern Georgia is continental with much lower annual precipitation (500–600 mm in the lowlands) and a mean temperature between 10–13 °C. In the mountainous areas mean temperature covers a range of −5 to 10 °C and precipitation varies from 800–1400 mm (World Bank, 2006).

The aim of this study is to provide a better understanding of annual and seasonal trends of temperature means and extreme events across Georgia. This is achieved by studying daily maximum and minimum temperature means and selected daily temperature extreme indices as well as its anomalies and trends within the periods 1961–2010, 1971–2010 and 1981–2010. Extreme temperature trends are calculated using a set of eight ETCCDI temperature extreme indices from homogenized daily maximum and minimum temperature series. The indices of temperature extremes considered in the present study were recommended by the Expert Team on Climate Change Detection Indices (ETCCDI) of the Commission for Climatology of the World Meteorological Organization (WMO).

The remainder of the paper is structured as follows. Section 2 of the present study describes the data quality control and homogenization as well as the temperature extreme indices and the analytical methods used in this study. Spatial patterns of annual temperature means and extremes and their changes between 1961 and 2010 over Georgia are presented in Section 3.1. Section 3.2 analyzes seasonal trends in mean and extreme temperature within the period 1961–2010. Section 4 summarizes the conclusions.

2. Data and methods

2.1. Data quality control

Daily minimum and maximum temperature series for 87 stations were kindly provided by the National Environmental Agency of Georgia (NEA). Data quality control has been carried out using the computer program RClimDex Software version 1.1 (available at: http://etccdi.pacificclimate.org). As a first step, temperature minimum and maximum time-series with more than 20% missing values within all analysis periods (1961–1990, 1961–2010, 1971–2010 and 1981–2010) were excluded. The analysis periods 1961–2010, 1971, and 1981–2010 were chosen to study changes in recent trends and to maximize the number of stations available for all periods. Quality was tested in order to identify and label potentially wrong values, and correct them from the time-series.